R E P O R T   R E S U M E S

ED 019 253   24   SE 004 694

A DEVELOPMENTAL STUDY OF MEDICAL TRAINING SIMULATORS FOR ANESTHESIOLOGISTS. FINAL REPORT.

BY- ABRAHAMSON, STEPHEN   DENSON, JUDSON S.
UNIVERSITY OF SOUTHERN CALIFORNIA, LOS ANGELES
REPORT NUMBER BR-5-0917   PUB DATE 31 JAN 68
CONTRACT OEC-6-10-135
EDRS PRICE MF-$1.00 HC-$8.72   216P.

DESCRIPTORS- *ANESTHESIOLOGY, *COMPUTER ASSISTED INSTRUCTION, *INSTRUCTION, *MEDICAL SCHOOLS, *MEDICAL STUDENTS, PROFESSIONAL TRAINING, SIMULATORS, TEACHING MODELS, GRADUATE STUDY, UNIVERSITY OF SOUTHERN CALIFORNIA, CALIFORNIA,

IN THIS STUDY, A COMPUTER-CONTROLLED PATIENT SIMULATOR (SIM ONE) WAS DESIGNED, CONSTRUCTED, AND TESTED FOR THE TRAINING OF ANESTHESIOLOGY RESIDENTS AT THE UNIVERSITY OF SOUTHERN CALIFORNIA SCHOOL OF MEDICINE. THE TRAINING INVOLVED THE DEVELOPMENT OF SKILL IN ENDOTRACHEAL INTUBATION. THE EXPERIMENT INVOLVED 10 ANESTHESIOLOGY RESIDENTS. FIVE WERE GIVEN TRAINING ON THE PATIENT SIMULATOR WHILE THE OTHER FIVE WERE INTRODUCED TO THEIR RESIDENCY IN THE USUAL MANNER. COMPARISONS BETWEEN SIMULATOR-TRAINED RESIDENTS AND THOSE IN THE CONTROL GROUP WERE MADE ON THE BASIS OF ELAPSED TIME FROM DATE OF ARRIVAL IN THE PROGRAM TO DATE OF PERFORMANCE AT A PROFESSIONAL LEVEL OF PROFICIENCY. THE OFFICIAL ANESTHESIA CHARTS OF THE HOSPITAL WERE USED AS THE SOURCE OF DATA. THE RESULTS INDICATE THAT THERE IS A TIME ADVANTAGE TO THE USE OF SUCH A SIMULATOR IN TRAINING ANESTHESIOLOGY RESIDENTS IN THE SKILL OF ENDOTRACHEAL INTUBATION. THE TIME ADVANTAGE DEMONSTRATED IS TWO-FOLD IN THAT (1) RESIDENTS ACHIEVE PROFICIENCY LEVELS IN A SMALLER NUMBER OF ELAPSED DAYS OF TRAINING, AND (2) RESIDENTS ACHIEVE A PROFICIENCY LEVEL IN A SMALLER NUMBER OF TRIALS IN THE OPERATING ROOM. THE FINAL REPORT FROM THE AEROJET-GENERAL CORPORATION, THE COMPANY WHICH DEVELOPED THE COMPUTER-CONTROLLED PATIENT SIMULATOR FOR THE UNIVERSITY OF SOUTHERN CALIFORNIA MEDICAL SCHOOL, IS PROVIDED. COMPLETE DESCRIPTIONS, INCLUDING PHOTOGRAPHS AND SCHEMATICS, OF THE HARDWARE SYSTEM, THE SOFTWARE SYSTEM, AND THE MANIKIN ARE INCLUDED. (DS)

~~5-0917-24~~
BR-5-0917
PA-24

ED019253

FINAL REPORT

Cooperative Research Project No. D-240, Contract OE 6-10-135

January 1, 1966 - December 31, 1967

A DEVELOPMENTAL STUDY OF MEDICAL TRAINING SIMULATORS FOR ANESTHESIOLOGISTS

Stephen Abrahamson, Ph.D.

and

Judson S. Denson, M.D.

The University of Southern California

School of Medicine

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
OFFICE OF EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL OFFICE OF EDUCATION POSITION OR POLICY.

January 31, 1968

SE 004 694

Supported by the U. S. Office of Education,
Department of Health, Education and Welfare

FINAL REPORT ON ANESTHESIOLOGY PROJECT

BACKGROUND

History of the Project

This project is the indirect result of the efforts of a Committee of the Los Angeles County Chamber of Commerce. The chairman of the Committee of Diversification, Tullio Ronzoni, was exploring possibilities of diversifying industrial efforts in Southern California, when he met with the director of the Division of Research in Medical Education at the University of Southern California School of Medicine and posed this question: "Are there ways in which we can use computers to facilitate medical education?" This innocent question was discussed at some length and an idea was born. The earliest formulation of the idea involved the creation of an operating-room set of conditions in which all of the monitoring equipment used by an anesthesiologist could be provided for a student to observe and respond to. The equipment, further, was to be under the control of a computer program in such a way that if a student requested oxygen or some drug, the appropriate patient response could be generated and would then produce changes in the monitoring equipment.

With this idea beginning to crystallize, the planning group was broadened to include J. S. Denson, M.D., chief of anesthesiology at the Los Angeles County General Hospital and head of the department of anesthesia in the USC School of Medicine. Further discussions then included computer science engineers at Aerojet General's Von Karman Center. During this phase of discussion, the concept was broadened to include a plastic replica of a real patient, capable of simulating certain life conditions.

In an effort to ascertain the state of the art, the planning group was broadened once more to include representatives of the Sierra Engineering Company. It seemed apparent that the project, as then conceived, was feasible from an engineering standpoint.

The original trio of planners, Stephen Abrahamson, Ph.D., J. S. Denson, M.D., and Tullio Ronzoni, then embarked upon a search for support. Their quest took them through many bureaus, divisions, and branches of the U. S. Public Health Service as well as the National Institutes of Health. While great interest in the project was expressed, tangible support for the project was lacking. The project was then described in a proposal submitted to the Cooperative Research Project of the United Stated Office of Education. Review of the proposal resulted in an award announced in late June, 1965, negotiated in August, 1965, and funded January 2, 1966.

The Original Purposes

Originally submitted as a "demonstration project" proposal, this study had three major purposes.

1. To test the feasibility of simulating a human being.
2. To test the effectiveness of using such a simulator in training.
3. To demonstrate the finished product of a patient simulator.

Simulating a human being for purposes of training health-care personnel demanded the amalgamation of a variety of physiologic dimensions and responses to both physical and pharmacologic stimuli. The test of feasibility selected was extremely complex - and deliberately so. The simulator was expected to "behave" as a human being at least with regard to the following.

1. Breathing.
2. Possessing a heartbeat.
3. Possessing a pulse.
4. Having blood pressure.
5. Opening and closing eyes.
6. Opening and closing mouth.

Furthermore, all of these were expected to vary within a normal range and to extremes under certain conditions. In addition, each of these was expected to give the appropriate response to the kinds of treatment that an anesthesiologist might administer.

The task selected for simulation was endotracheal intubation and the administration of anesthetic agents both intravenously and through the airway. This task was selected because of the rigor of the test of feasibility and not because of the possibility of demonstration of cost-effectiveness of training.

A test of effectiveness was included in the original project description, however. This test involved a very limited number of beginning anesthesiology residents primarily for the purpose of demonstrating effectiveness and not for the purpose of a rigorous, experimental study of cost-effectiveness benefits in training. In fact, the very terms of the original project virtually prevented any demonstration of cost-effectiveness through the physical separation of the simulator from the site of the hospital and medical school.

Ultimately, it was expected that the working model of the patient simulator would be used in demonstrations particularly for anesthesiologists and for other medical educators as well. The demonstration was to be accomplished at Aerojet General's Von Karman Center, 25 miles distant from the L. A. County-USC Medical Center.

Specific Purposes

The major objective of this project is the demonstration of the feasibility, practicality, and utility of the use of a computer-controlled simulated patient in the training of anesthesiologists. More broadly, the objective is to demonstrate the important contribution to medical education that can be made by the application of computer-controlled patient simulators.

✓Subsidiary objectives of this demonstration project include the determination of the ultimate educational value to the students, to instructors, and to medical education in general. Controlled experimental research will compare the learning resulting from the use of the simulated patient with that which takes place ordinarily without the use of this device. Criteria by which judgments will be made concerning the value of the simulated patient will include (1) the amount of learning, (2) the amount of time required for a given unit of learning, (3) the immediate and ultimate cost of providing the simulated patient, (4) student and faculty satisfaction, and (5) the extent to which potential harm and discomfort to patients are avoided.

The Award of the Contract

As finally negotiated, the contract called for the development and demonstration of a computer-controlled patient simulator and its ultimate test with beginning anesthesiology residents. The original specifications can be found in the final report submitted by the subcontractor, Aerojet

General Corporation. The nature of the subcontract with Aerojet General's Von Karman Center was described as a "best-effort" contract, because of the many unknowns in the further development of simulations.

The original schedule called for work to begin on September 1, 1965, and to be completed by August 31, 1967.

Delays in negotiation of the contract and receipt of the final signed contract necessitated changing the time schedule. Work did not begin until January 1, 1966, and the closing date of the contract was changed, therefore, to December 31, 1967. Since the arrival of new anesthesiology residents at the Los Angeles County Hospital ordinarily begins on July 1 of each year, extra pressure was placed on the production and developmental stages. According to the original schedule, the production and initial testing of the simulator were to cover a period of 20 to 22 months. Under the revised schedule, these phases were reduced to a period of time significantly shorter: 18 months.

DEVELOPMENT OF THE SIMULATOR

Original Specifications

I. General

The following specification is for an actuated, articulated manikin to be used in conjunction with a general purpose computer system to simulate certain phases of the process of anesthetizing a human patient preparatory to medical surgery. It is desired that this manikin, when given control signals originating in the computer and based upon stimuli sensed by transducers within the manikin, will have reactions which closely resemble the reactions of an actual patient under similar stimuli. To this end, the following requirements are to be used as a minimum. It is recognized that this program is developmental and a close working relationship between the principles is required.

II. Design Requirements

A. Outer Appearance

1. The manikin shall resemble a normal adult male in size. The manikin shall recline on a base resembling an operating table. The upper half of the manikin shall be lifelike in appearance from the abdomen to the top of the head. The lower half of the manikin shall be covered with a sheet and need not be lifelike in appearance. The back of the manikin shall be lifelike from the shoulder blades to the top of the head.

The left arm shall be extended on a board approximately 80° from the plane of the body. This arm shall be capable of accommodating an appropriately placed simulated intravenous catheter through which fluids may be administered.

The right arm shall be placed along the manikin's side and shall be capable of accepting a blood pressure cuff and stethoscope.

Fingers on the hand shall curve in a relaxed position and contain fingernails which are realistic in appearance and touch.

The head and face shall be realistic and lifelike in appearance. The head shall have realistic eyebrows and eyelashes. The head shall be wrapped with a removable and washable linen cloth. Realistic hair shall be affixed in places which may not be completely covered by the head cloth. The eyes, nose and mouth shall have a realistic external appearance. Eyelids shall be realistic in appearance both when covering the eye and when retracted to uncover the eye.

The skin shall resemble human skin as closely as possible in appearance and feel. If possible, the skin shall be as mobile on the underlying supporting structures as the human skin on the underlying bony structures. The skin shall be capable of stretching and resuming its original shape when movable members of the manikin are manipulated (for example, the skin of the neck when the head is extended on the neck and tilted back). Skin coloring shall be normal for conditions of the simulated patient. (See section on coloring.)

B. Internal Appearance

The mouth and throat including the esophagus and extending at least 10 cm below the opening into the posterior pharynx, the trachea and larynx down through and including approximately 4 cms of each main stem bronchus and the complete oral cavity including teeth, lips, tongue, palate and pharynx shall be as realistic in appearance, scale and mechanical compliance as possible. The mucous membranes shall be smooth, glistening and stretchable as are those of a human being. Coloring shall be appropriate as described in a later section.

The upper incisors shall be capable of removal with a backward force against the front of them of greater than 5 pounds. These shall be capable of being replaced after being pushed out by this force.

The nose shall have two nasal passages separated by the septum, be realistic in appearance when viewed through the openings (approximately the first 2 - 3 cm of the nasal passage) which shall connect the external openings of the nose to the posterior pharynx. These passages shall accommodate a 9 mm diameter plastic catheter allowing it to slide smoothly through the passageway into the posterior pharynx. Pinching the nose shall cut off these air passages.

C. Internal Supporting Structure and Articulations

The internal supporting structure of the manikin shall be such as to provide the realism in the following possible motions of the parts:

1. The Jaw

The jaw shall open and close on a pivot in one plane only. When fully open the edges of the upper and lower teeth shall be separated by a distance of 5 cm. The pivot point of the jaw shall be movable to a distance of 1 cm in the direction of the lower jaw. The pivot point shall return to neutral position when released. With no actuation the lower jaw shall sag open such that a distance of 2 cm is presented between the edges of the teeth. In this position, the lower lip shall protrude over the lower teeth a distance of 1/2 to 1 cm. (See section on actuation). The lip shall be so constructed that closure of the jaw shall cause the lip to pull back enough to prevent "biting" the lip.

2. The "Spinal" Action

The "spinal" action shall allow the head to be moved and positioned realistically in the pitch plane. Rotation of the head of from 10^{o} to 15^{o} from normal is desirable but not absolutely necessary. The neck must be flexible on the torso to approximately 15^{o} from horizontal. With the manikin's head raised 15 cm on a pillow, the head must extend (extend meaning to pitch back, flex to pitch forward on the neck) on the neck far enough so that when a laryngoscope is properly placed a full view of the glottic opening will be obtainable. The head shall flex in this position until the chin of the closed jaw is from 3 to 5 cm of the chest wall.

3. The Tongue

The tongue should be constructed in as nearly a normal manner as possible closely resembling the total structure as pictured in anatomy textbooks. This structure is very thick at the base and tapers to a tip. It shall be mobile in all directions over approximately the front half. It must be sufficiently mobile so that in the fully relaxed position of the jaw the tongue may fall back or be pushed back into the posterior pharynx to occlude the airway. It should be so attached to the jaw at the base so that when the jaw is lifted, the tongue will no longer occlude the airway.

4. The Larynx

The epiglottis shall be constructed of a relatively stiff although somewhat flexible material and shall appear as seen in anatomy textbooks. With the manikin in the supine position, the epiglottis shall hang down partially obscuring the trachea opening. Pressure applied with the tip of the laryngoscope at the juncture of the epiglottis and the tongue shall cause the epiglottis to curl up on the tip of the laryngoscope. The glottis, both true cords and aryepiglottic fold must open and close from a range of tight closure to full flacid opening. When fully open an opening of approximately 1.5 cm between the cords and 2.5 cm from front to back of the trachea shall be exposed. With the vocal cords fully closed, the aryepiglottic folds shall be capable of closing over the cords.

5. The Esophagus

The opening into the pharynx from the esophagus shall be in the just closed position. However, the pressure of the tip of an endotracheal airway on this opening shall cause it to open to admit the airway.

6. The Eyelids

The eyelids shall be capable of moving in a realistic manner to the open and closed positions.

7. The Pupils

The pupils of the eyes shall be capable of constricting or dilating through a diameter range of 1 mm to 8 mm.

8. The Eyebrows

Eyebrows and forehead shall be capable of wrinkling.

9. The Shoulder Muscles

The shoulder muscles shall be capable of a twitching simulation, that is, rippling up and down a small but visually noticeable distance.

10. The Chest

The chest shall be capable of moving up and down in response to respiration. This motion shall be as near normal as possible. The maximum simulated expansion of the chest shall be about 5 cm resulting in an upward motion of the front of the chest wall of about 2 cm maximum. Both sides of the chest shall be capable of independent motion as well as synchronous motion.

11. The Abdomen

The abdomen shall be capable of expansion and contraction with the chest in simulated breathing. In addition, the abdomen must be capable of expansion from accidental inflation during the aided breathing period of the operation. Motion of the abdomen, independent of chest motion, shall be possible.

Difficulties Encountered

The major difficulties encountered during the development of the hardware involved, for the most part, finding the appropriate plastic to simulate skin realistically; designing the kind of operation of the lungs that would allow the physical responses to manipulation of the reservoir bag, as well as the measurement of volume of gases in and out; construction of the jaw movement to accommodate realistically to manipulation by hand of anesthesiologist as well as laryngoscope; and construction in the neck to allow for a realistic display of anatomy of the trachea with flexion. In addition, difficulty was encountered in attempting to meet the specification of skin color change with lack of oxygen. This last requirement had to be abandoned because of the inability to solve engineering problems involved within the cost limitations. Other problem areas might have proven to be major obstacles had it not been for the imaginative and innovative engineering efforts of both the project manager, A. Paul Clark, and the project engineer, Leonard Taback, of Aerojet General's Von Karman Center. Each of the major problems to be solved seemed to become nothing more than routine challenge for these brilliant engineers. This kind of effort involved their studying anatomy and physiology as well as observing surgery in the operating room at Los Angeles County General Hospital. Each set of physiologic facts and pharmacologic responses was reduced to mathematic expressions which allowed for computer programming to control the actions of the manikin itself in a realistic manner. Prior to the development of an interface between the manikin and the program, these engineers developed a complete simulation of the total simulator - a simulation which allowed all concerned to study the interactions and make modifications relatively inexpensively. The same kinds of modifications introduced after the production of the complete simulation system would have demanded far more expensive changes. The efforts of these two men in particular and of the entire Computer Sciences Division of Aerojet General's Von Karman Center have tended to be minimized in much of the popular publicity which followed the "unveiling" of Sim One, as the simulator is now called. Therefore, it is important to record these special notes of recognition: the success of this enterprise is directly the result of the inventive and ingenious efforts of these engineers.

Delivery of the First Product

The manikin itself was to be delivered by a subcontractor, Sierra Engineering Company, by January 2, 1967. Don Carter, project engineer supervised the efforts at Sierra Engineering Company and found many more technical difficulties than had been anticipated. Consequently, delivery was delayed somewhat and, more importantly, the product did not meet minimum specifications demanded.

The major deficiencies noted included the following. After three or four days, the skin began to change color in large splotches. The cause of this color change was attributed to improper "curing" of the plastic itself. Since realism was important in the project, this deficiency had to be corrected.

A second deficiency was in the movement of the jaw. The mechanisms controlling this did not allow for sufficient easing of jaw tension in opening the mouth. Since the realism of this kind of movement is an essential in the simulation necessary for teaching anesthesiologists endotracheal intubation, this deficiency also had to be corrected.

Certain other less important deficiencies were noted, dealing with realism of appearance: the opening and closing of the eyes, the appearance of the hair, the appearance and feel of the teeth, and the like. Since major deficiencies had to be corrected, improvement of these features were also to be accomplished.

The manikin, itself, therefore, was returned to Sierra Engineering Company for these modifications. A new delivery date of March 1, 1967, was set.

Delivery of the Second Model

An improved version was delivered by Sierra Engineering Company at the beginning of March, 1967. While there was significant improvement in many of the aspects that had needed correction, deficiencies were still noted. The model, however, allowed for the production of a motion picture film, illustrating the capability of this simulation system. Following the production of that film, the manikin was once more returned to Sierra Engineering for further correction. The new delivery date set for the final product was June, 1967.

The first official public reporting of progress in this project was made in New York City on March 17, 1967, at the Annual Meeting of University Professors of Anesthesiology. At that meeting, Dr. Denson described the project and showed a film which illustrated the remarkable capabilities of this simulator. It was at this reporting that the simulator was given the name which has stayed with it: Sim One. A great deal of publicity ensued following this report; Sim One was described in some detail and national newspaper coverage including the New York Times of March 18, 1967. Time reported Sim One on March 24, 1967. Walter Cronkite included a special report in his evening CBS News Report of March 17, 1967. It is especially important to note that the anesthesiologists present at the meeting in New York

City were enthusiastically favorable in their response to the authenticity and realism of the simulation as well as to the immediately predictable training advantages.

Delivery of the Final Product

The final product, now operating as Sim One, was delivered in June, 1967, and represented the results of close cooperative efforts among J. S. Denson of USC, Paul Clark and Leonard Taback of Aerojet Engineering Corporation, and Don Carter of Sierra Engineering Company. The final modifications could not have been achieved without this kind of integrated effort. Despite some minor deficiencies still apparent in the product delivered in June of 1967, the total simulation was deemed adequate for the effectiveness testing to begin on July 1, 1967. Indeed, the final version far exceeds the most optimistic anticipations of all those concerned.

During this final month prior to the beginning of effectiveness tests, engineers at Aerojet General's Von Karman Center performed final modifications and developmental tests.

Thus in June of 1967, feasibility of this kind of simulation was demonstrated conclusively in the successful operation of Sim One, a computer-controlled patient simulator, capable of producing the physiologic and pharmacologic responses called for in the original specifications. Demonstrations of this feasibility were made to members of the faculty of the school of medicine as well as to members of the resident staff of anesthesiology of the Los Angeles County General Hospital prior to the beginning of the test of effectiveness in training. The final report submitted by Aerojet General's Von Karman Center includes all final drawings, specifications, and computer programming and appears immediately following this text.

TEST OF EFFECTIVENESS

Design of the Study

The anesthesiology resident training program at the Los Angeles County General Hospital is one of the largest in the country. At any given time, there are more than 24 residents in training. It was anticipated that twelve new residents would arrive after July 1, 1967. These twelve were to be paired for purposes of study, one of each pair to be afforded training on the simulator and the other to engage in the usual training procedures without the benefit of experience on the simulator. Decision as to which member of each pair would be given training on the simulator was made by a flip of a coin. The pairing itself was an artifact of chance in that not all twelve new residents arrived on July 1, 1967. Rather, new residents were added as they arrived, arrival time being any time between the late spring of 1967 and the fall of 1967. Eventually, incidentally, only five pairs were used because one pair of residents had had extensive experience in endotracheal intubation during the year prior to beginning their residency training, having accomplished more than 150 intubations respectively.

Thus, the experiment involved ten anesthesiology residents. Five residents were given training on Sim One while the other five were introduced to their residency in the usual manner. The time spent on Sim One ranged from a minimum of 5-1/2 hours for one resident to 9-1/2 for another. The distance separating Sim One from the Los Angeles County General Hospital, however, necessitated several visits by each resident in order to accomplish this. Thus, the total time elapsed ranged up to two weeks. Had Sim One been located in the Los Angeles County General Hospital, the training period on Sim One would not have extended more than two or three days each.

The design of the study necessitated some measure of proficiency in endotracheal intubation. The criteria to be applied were developed by the Department of Anesthesiology and refined in such a way as to make possible the construction of a criterion check list. The plan was to observe each of the ten residents in the operating room every time he was required to participate in endotracheal intubation. In addition, the plan called for similar observation of the five simulator-trained residents during their training runs on Sim One. Comparisons between simulator-trained residents and those in the "control group" were to be made on the basis of elapsed time from date of arrival in the program to date of performance at professional level of proficiency.

The criteria of performance were transformed into a 53-item check list. (See Figure 1.) The items in this check list are arranged in sequential order of all of the actions which much be accomplished by an anesthesiology resident in the performance of endotracheal intubation. It was expected that the arrangement of items would allow for a kind of Guttman-like scale; that is, if an anesthesiologist failed to perform one behavior at a professional level of proficiency, his instructor would have to interrupt him and continue the process himself. Thus, it was expected that the variable to be measured would be that of time along with how far along in the check-list behaviors the resident was able to go without instructional interruption.

In an attempt to avoid the usual difficulties associated with the use of rating scales, the criterion level of performance was set at "professionally acceptable" and allowed for no in-between judgments. Interruption or invention would be the unequivocal indication of anything less than the accepted criterion level of performance.

FIGURE I

ANESTHESIOLOGY CHECK LIST

Resident Name ____________________

Instructor Name ____________________

Date ____________________

Instructor Intervention at Step # ______________

Number of Months in Training ______________

COULD NOT OBSERVE	LESS THAN PROFESSIONAL	PROFESSIONAL	
☐	☐	☐	1. Check Suction
☐	☐	☐	2. Check all gases turned on
☐	☐	☐	3. Check system air tight
☐	☐	☐	4. Check all gases connected to proper yoke
☐	☐	☐	5. Check laryngoscope light works
☐	☐	☐	6. Check cuff works
☐	☐	☐	7. Check all equipment present
☐	☐	☐	8. Check pentothal
☐	☐	☐	9. Check SSC
☐	☐	☐	10. Check Vasopressor
☐	☐	☐	11. Observe and record BP
☐	☐	☐	12. Observe and record P
☐	☐	☐	13. Observe and record R
☐	☐	☐	14. Check mask fit - no leaks

COULD NOT OBSERVE	LESS THAN PROFESSIONAL	PROFESSIONAL	
☐	☐	☐	15. 5 minutes Oxygen
☐	☐	☐	16. Check strap not "to tight"
☐	☐	☐	17. Test dose pentothal
☐	☐	☐	18. Check BP after 60" - record
☐	☐	☐	19. OT dose of pentothal
☐	☐	☐	20. OT dose of SSC
☐	☐	☐	21. Assisted respiration - Controlled respiration
☐	☐	☐	22. Place OT and scope before mask off
☐	☐	☐	23. Mask off to 1st breath - time with stop watch
☐	☐	☐	24. Scope in left hand
☐	☐	☐	25. Head elevated, extended
☐	☐	☐	26. Mouth opened with right hand
☐	☐	☐	27. Lips cleared as scope inserted
☐	☐	☐	28. Scope blade to right, then left, tongue to left
☐	☐	☐	29. Scope to mid-line
☐	☐	☐	30. Epiglottis elevated
☐	☐	☐	31. Upper teeth not touched with scope
☐	☐	☐	32. Laryngoscope - scope lifted in direction of handle (no prying)
☐	☐	☐	33. Tube picked up without taking eyes from larynx
☐	☐	☐	34. Tube held in finger tips
☐	☐	☐	35. Tube inserted gently

COULD NOT OBSERVE	LESS THAN PROFESSIONAL	PROFESSIONAL	
☐	☐	☐	36. Tube inserted proper depth
☐	☐	☐	37. Stylet removed partially as tube inserted
☐	☐	☐	38. Bite block inserted as scope removed
☐	☐	☐	39. Stylet out
☐	☐	☐	40. Hook-up and 1st breath
☐	☐	☐	41. Tape at corner of mouth
☐	☐	☐	42. Cuff inflated - listen for leak as reservoir bag squeezed
☐	☐	☐	43. Listen to chest - breath sounds both sides
☐	☐	☐	44. Observe both chests rise equally
☐	☐	☐	45. 2nd tape to tube
☐	☐	☐	46. Tape bite block separately
☐	☐	☐	47. Breath for pt. between each maneuver
☐	☐	☐	48. Check BP, P, immediately after 1st breath and record
☐	☐	☐	49. Secure Y-piece and tubing
☐	☐	☐	50. Check BP, P again and record
☐	☐	☐	51. More pentothal to prevent awakening after SSC wears off
☐	☐	☐	52. Check BP 60" after Pentothal
☐	☐	☐	53. Continue ventilation until adequate (AR and/or CR)

General Comments: ____

____

____

____

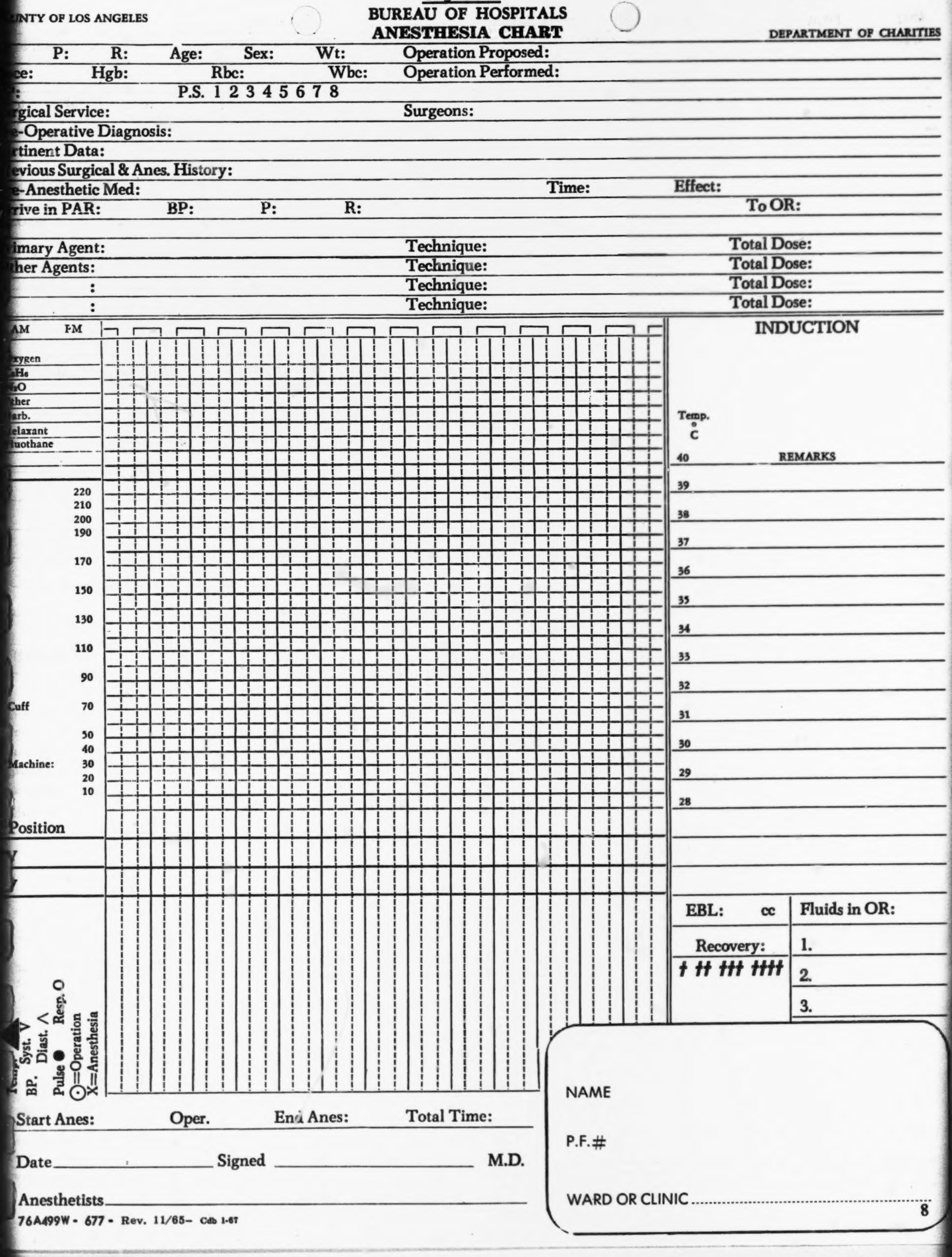
Modification of Plans

Several difficulties were encountered in the application of this check list. In the first place, when anesthesiology residents performed unimportant aspects at something less than "professionally acceptable" levels, they were often not interrupted by their instructors. Thus, the check list had to be reexamined in an effort to identify those aspects of endotracheal intubation which always demanded intervention if not performed correctly. Secondly, it was discovered that intervention or interruption could take place at any point in the total procedure but then be followed immediately by the instructor's allowing his resident to resume from that point on. Thus, the resident's total efforts did not end at the point of interruption or intervention, necessarily. Finally, and most importantly, it was discovered that the staff of the anesthesiology department were not completing check lists every time one of the ten residents was performing endotracheal intubation. In fact, despite every effort of the Project staff, a totally insufficient number of check lists were completed. Unfortunately, the nature of work in the operating room did not allow for discovery of this fact until correction was almost impossible. In addition, the same operating room load did not allow for correction even after discovery.

Thus, the use of the check list had to be abandoned in favor of another approach. The investigators turned, instead, to the official anesthesia charts of the Hospital as the source of data. Each anesthesiologist is obliged to maintain a complete record of the administration of anesthesia during surgery procedures as part of the official Hospital records. These anesthesia charts include a sufficient amount of information concerning the activities of the anesthesiologist to allow for some judgment to be made concerning his proficiency. Figure 2 is an example of such a chart.

The anesthesia charts of all endotracheal intubations performed by the ten residents in this study were subject to critical appraisal. The name of the resident and the date of the intubation were completely concealed and each chart was submitted to the Department of Anesthesiology with this question posed: "On the basis of what you see on this chart, would you be willing to trust the anesthesiology resident in an operating room without supervision?" Thus, each endotracheal intubation was rated as professionally acceptable or not on the basis of official records. The charts, thus, received a "plus" rating for professionally acceptable performance and a "minus" rating for unacceptable performance. In all, 1,220 charts were reviewed and rated. It may be important to note that even the research assistant who scotch taped the concealing tabs over names and dates did not know who the experimental or control group members were. Thus, in a sense, a "double-blind" experiment was performed.

Figure 2



UNTY OF LOS ANGELES

BUREAU OF HOSPITALS
ANESTHESIA CHART

DEPARTMENT OF CHARITIES

P: R: Age: Sex: Wt: Operation Proposed:

ce: Hgb: Rbc: Wbc: Operation Performed:

: P.S. 1 2 3 4 5 6 7 8

rgical Service: Surgeons:

e-Operative Diagnosis:

rtinent Data:

evious Surgical & Anes. History:

e-Anesthetic Med: Time: Effect:

rive in PAR: BP: P: R: To OR:

imary Agent: Technique: Total Dose:

ther Agents: Technique: Total Dose:

: Technique: Total Dose:

: Technique: Total Dose:

AM PM

xygen
₂H₄
₂O
ther
arb.
elaxant
luothane

220
210
200
190
170
150
130
110
90
Cuff 70
50
40
Machine: 30
20
10

Position

INDUCTION

Temp. °C

REMARKS

40
39
38
37
36
35
34
33
32
31
30
29
28

EBL: cc

Fluids in OR:
1.
2.
3.

Recovery:
† †† ††† ††††

Temp. Δ
BP. Syst. V Diast. Λ
Pulse ● Resp. O
⊙=Operation
X=Anesthesia

Start Anes: Oper. End Anes: Total Time:

Date____________ Signed ____________ M.D.

Anesthetists____________

76A499W - 677 - Rev. 11/65- Cdb 1-67

NAME

P.F.#

WARD OR CLINIC..........

8

POST ANESTHESIA RECOVERY RECORD

M	PM
mp.	220
0	210
9	200
8	190
7	
6	170
5	
4	150
3	
2	130
31	
30	110
29	
28	90
Cuff	70
	50
	40
	30
	20
	10

IRWAY

es No

Pharyngeal

rotracheal

asotracheal

Tracheotomy

Medications	Dose	Route	Nurse
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			

Dressing Drainage		Oxygen
		Nasal
Yes	No	Tent
Type		Mask
		IPP

REMARKS:

POST OPERATIVE COURSE

FLUIDS	5% D/W	BLOOD	OTHERS	OUTPUT	
				URINE	OTHER
DURING OPERATION					
IN PAR					
TOTAL					
CC LEFT IN BOTTLE					

	DATE	TIME	CONDITION
Admission			
Discharge			

Nurse

CONDITION SIGNATURE: M.D. SIGNED: M.D.

urname First Na Middle Name P.F. # Ward Date

Following completion of the rating process, the anesthesia charts were then sorted according to resident's name and arranged in chronological order from the date of the first intubation completed by the resident to that of the last intubation within the time period of the study. Three different levels of performance were selected and two variables were studied. The investigators decided to see how many operating-room trials were necessary for a resident to achieve four consecutive plus ratings as a first criterion. Secondly, the investigators believed that achievement of seven out of eight consecutive plus ratings might be another indication of achievement. Finally, the investigators also examined the number of trials necessary to achieve nine out of ten consecutive plus ratings. In addition, the investigators examined the number of elapsed days between the first endotracheal intubation in the operating room and achievement of each of these three criterion levels. Table 1 presents the list of the criteria studied.

Statistical analysis involved the use of analysis of variance (F-ratio), using a randomized block design for all analyses. And, despite the very small number of subjects, statistical significance was tested.

Findings

Data are presented in Tables 2 through 7 and Figures 3 and 4. Table 2 shows the number of trials necessary for each resident in the study to achieve four consecutive plus ratings. The experimental group is listed in the left-hand column and the control group, in the right-hand column. The mean number of trials necessary to achieve four consecutive plus ratings was 9.6 for the experimental group and 18.6 for the control group. The small number of cases, however, resulted in a lack of statistical significance in this difference.

The smallest difference to be noted is in the number of elapsed days to achieve four consecutive plus ratings. (See Table 3.) As the more rigorous criteria are applied (seven out of eight and nine out of ten) the differences tend to be larger and, indeed, reach statistical significance in the last criterion level, nine out of ten consecutive plus ratings. Table 6, for instance, shows that the mean number of trials necessary to reach this criterion level was 30.0 for the experimental group and 59.8 for the control group. This difference is significant at the .01 level. Table 7, furthermore, indicates that the mean number of elapsed days necessary to achieve this criterion level was 45.6 days for the experimental group and 77.0 days for the control group - a difference significant at the .05 level. Summary data are presented graphically in Figure 3 (number of trials necessary to reach each of the three criterion levels) and Figure 4 (number of elapsed days necessary to reach each of the three criterion levels).

Table 1

List of Mastery Criteria

1. Number of trials to get 4 consecutive plus ratings.
2. Number of elapsed days to get 4 consecutive plus ratings.
3. Number of trials to get 7 out of 8 consecutive plus ratings.
4. Number of elapsed days to get 7 out of 8 consecutive plus ratings.
5. Number of trials to get 9 out of 10 consecutive plus ratings.
6. Number of elapsed days to get 9 out of 10 consecutive plus ratings.

Table 2

Number of Trials to Get 4 Consecutive Plus Ratings

Pairs	Experimental	Control
A	4	31
B	4	12
C	25	22
D	9	4
E	6	24
Mean	9.6	18.6

F = 2.165 (N.S.)

Table 3

Number of Elapsed Days to Get 4 Consecutive Plus Ratings

Pairs	Experimental	Control
A	6	36
B	4	11
C	45	28
D	13	4
E	17	35
Mean	17.0	22.8

F = .46 (N.S.)

Table 4

Number of Trials to Get 7 out of 8 Consecutive Plus Ratings

Pairs	Experimental	Control
A	19	31
B	28	67
C	40	71
D	28	24
E	27	26
Mean	28.4	43.8

F = 3.25 (N.S.)

Table 5

Number of Elapsed Days to Get 7 out of 8 Consecutive Plus Ratings

Pairs	Experimental	Control
A	23	36
B	40	103
C	62	72
D	47	44
E	42	34
Mean	42.8	57.8

F = 1.41 (N.S.)

Table 6

Number of Trials to Get 9 out of 10 Consecutive Plus Ratings

Pairs	Experimental	Control
A	21	46
B	30	69
C	40	71
D	30	70
E	29	43
Mean	30.0	59.8

$F = 38.3$ ($p < .01$)

Table 7

Number of Elapsed Days to Get 9 out of 10 Consecutive Plus Ratings

Pairs	Experimental	Control
A	26	50
B	41	108
C	62	72
D	49	90
E	50	65
Mean	45.6	77.0

$F = 9.2$ ($p < .05$)

Table 8

Mastery Criterion Means and F-Ratios

Mastery Criterion	Experimental (N=5)	Control (N=5)	F-Ratio
A (trials to 4 consecutive)	9.6	18.6	2.165
B (days to 4 consecutive)	17.0	22.8	.46
C (trials to 7/8)	28.4	43.8	3.25
D (days to 7/8)	42.8	57.8	1.41
E (trials to 9/10)	30.0	59.8	38.3 **
F (days to 9/10)	45.6	77.0	9.2 *

* $p < .05$

** $p < .01$

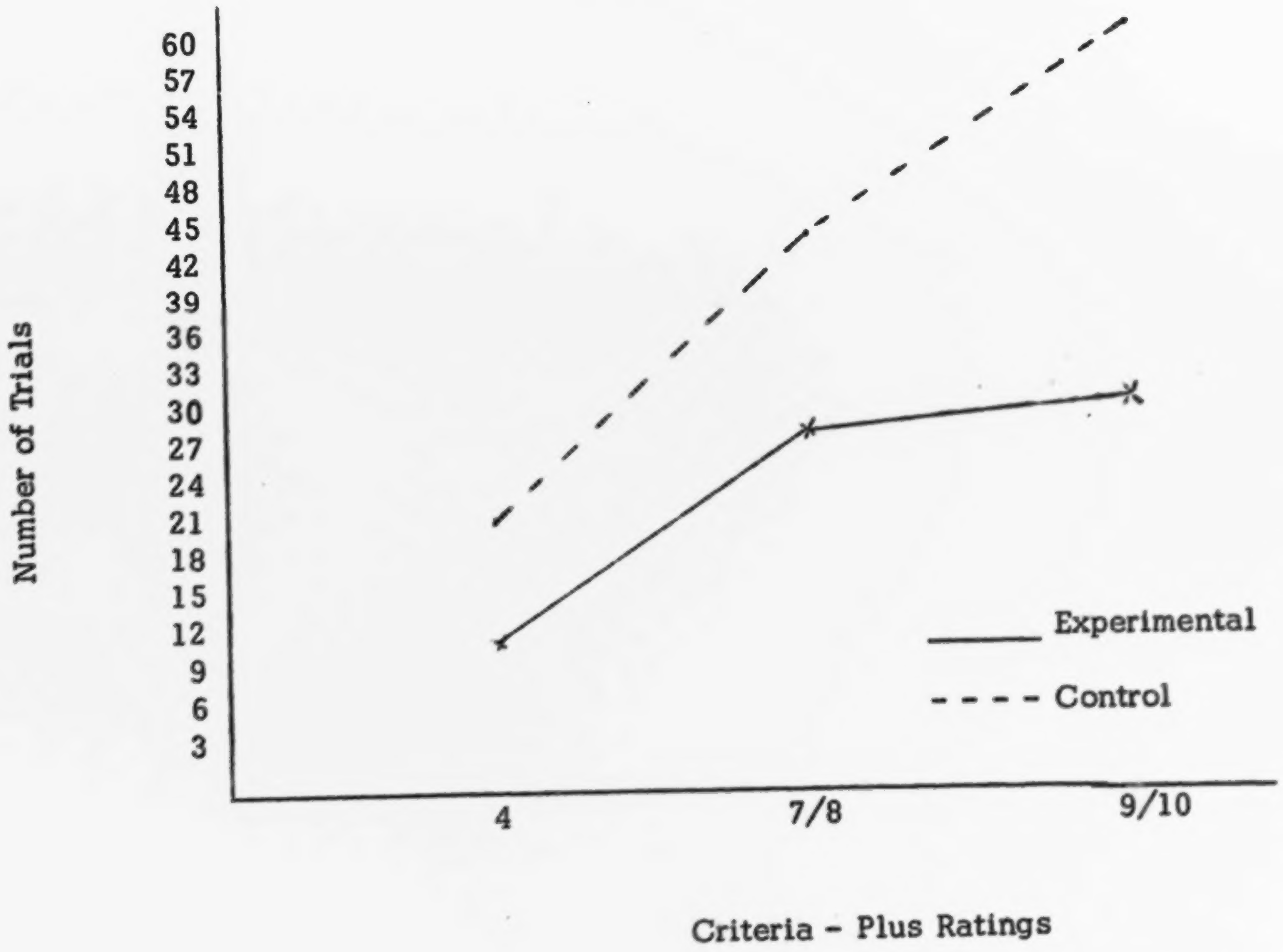


Figure 3 - Mean Number of Trials to Reach Criterion Levels

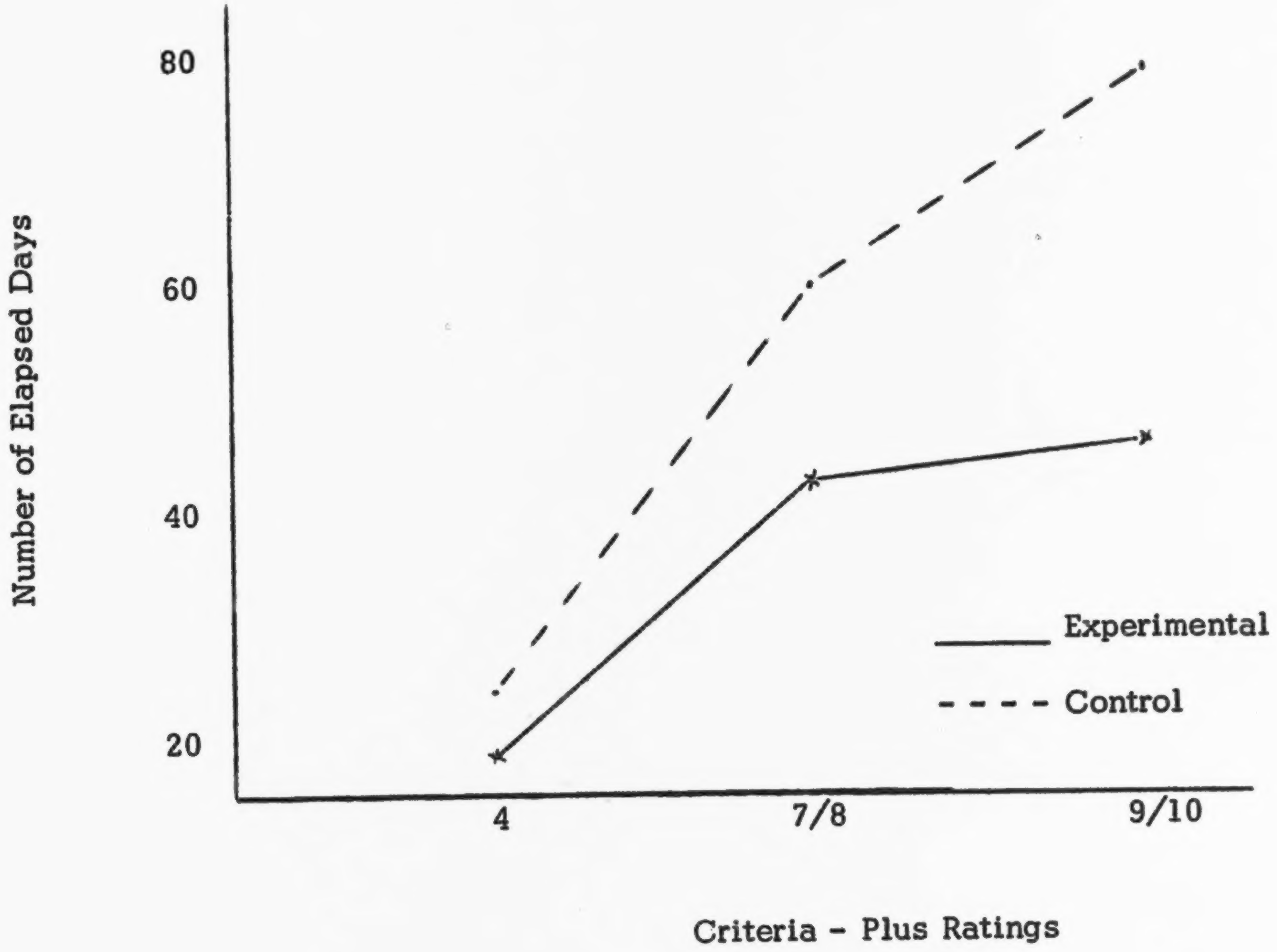


Figure 4 - Mean Number of Elapsed Days to Reach Criterion Levels

CONCLUSIONS

Despite the lack of statistical significance in several of the analyses, the investigators conclude that there is an advantage in time in the use of this computer-controlled patient simulator in the training of anesthesiology residents. Residents using the simulator tend to arrive at accepted professional levels of performance in fewer elapsed days and in a smaller number of trials in the operating room than do residents who did not have a training period on the simulator.

Discussion

The results of the study are all in the hypothesized direction even though they fail to reach the level of statistical significance in four out of six of the analyses. This failure to reach statistical significance is due to the large within-group variability and the small number of subjects involved in the study. The differences in means for each of the criterion levels are still substantial, if not significant.

The figures, perhaps, do not tell the whole story even here. For instance, when considering number of trials to achieve the criterion levels, one must keep in mind that lack of achievement of a "plus rating" signifies that some aspect or aspects of total performance were so lacking in quality that an experienced anesthesiologist stated, "I would not trust this man in the operating room without supervision." Thus, potential discomfort or even harm is posed to the patient during that endotracheal intubation. Thus, significantly less threat to patient welfare is posed by residents who have been trained on the patient simulator. Another look at Table 2, for instance, makes this quite clear.

The mean number of trials necessary for simulator-trained anesthesiology residents is 9.6 as compared to 18.6 for those not trained on the simulator. Thus, one might say that on the average nine more patients were posed with minor or less minor threat by each beginning anesthesiology resident not trained on the simulator before that resident achieved skill enough to perform four consecutive professionally acceptable endotracheal intubations. These differences grow as the criterion level becomes more exacting.

Another way of looking at the data, however, is in potential time-saving in training. Again, despite the lack of statistical significance, the differences are all in the hypothesized direction. More importantly, however, Table 7 demonstrates a 22-day saving, on the average, in the achievement of nine out of ten consecutive plus ratings - the most exacting criterion applied. Thus, by extrapolation, beginning anesthesiology residents might be expected to achieve this level of professional competence in a saving of 22 days over a period of 77 days. If all of the skilled tasks to be learned by anesthesiology residents could be taught through simulators, one can speculate that the achievement of these skills might be accomplished in less than three-quarters of the time now needed. It is important to remember that not only would this time be saved, patients would be spared potential discomfort and harm in significant numbers as well.

A final word concerning this experiment is simply a reminder that the entire study was undertaken not in an effort to test the cost-effectiveness of using a computer-controlled simulator for training health personnel but rather to test and demonstrate the feasibility of simulating a living human being for purposes of training health care personnel. This demonstration has been achieved without question. More than that, the educational experiment has also been accomplished, albeit with small numbers of subjects.

SUMMARY

In this study, a computer-controlled patient simulator was designed and built by Aerojet General Corporation under contract to the University of Southern California with a contribution by Sierra Engineering Company. Its educational potential was then tested by the University of Southern California School of Medicine. The results of the experiment suggest unequivocally that there is a time advantage to the use of such a simulator in training anesthesiology residents in the skill of endotracheal intubation. The time advantage demonstrated is twofold. (1) Residents achieve proficiency levels in a smaller number of elapsed days of training, thus effecting a saving of time in training of personnel. (2) Residents achieve a proficiency level in a smaller number of trials in the operating room, thus posing significantly less threat to patient safety. The small number of subjects in the study and the large within-group variability were responsible for lack of statistical significance in four out of six of the analyses; however, all differences were substantial and in the hypothesized direction.

At the present time, Sim One is virtually inoperative because of lack of funds for continued development and study. At this stage, Sim One still requires the hybrid computer facilities at Aerojet General's Von Karman Center for its operation. Thus, 25 miles separate the simulator and its potential student body. A special purpose computer to drive Sim One is included in Phase 2 of this study of simulation but is as yet not forthcoming because of lack of continued support. Proposals are being considered by two private foundations.

Experience with the development of Sim One suggests that future study should be organized in a continuous developmental study approach rather than the production of one more simulator at a time. A minimum of three years is really indicated by the nature of the work done to date.

More than that, however, a five-year period is necessary to achieve the kinds of gains that should now be possible after this exploration of feasibility. The University of Southern California School of Medicine hopes to establish a Center for such continuing studies.

PERSONNEL INVOLVED IN THE STUDY

From the University of Southern California School of Medicine:

Stephen Abrahamson, Ph.D., Director
Division of Research in Medical Education, and
Project Co-Director

Judson S. Denson, M.D., Professor of Surgery
(Anesthesiology, Chairman) and Project Co-Director

Edward Gorski, Research Assistant
Gerry O'Brien, Research Assistant

From Sierra Engineering Company Medical Products Division:

Tullio Ronzoni, Senior Technical Specialist
John Alt, Sculptor
Earl Briggs, Mechanical Engineer
Don Carter, Project Engineer

From Aerojet-General Corporation, Electronics Division, Azusa, California:

A. Paul Clark, Project Manager
Leonard Taback, Project Engineer
Harry Loberman, Programmer
Hank Perez, Computer Operator
Wallace Falkowski, Technician
Charles Killian, Technician

ELECTRONICS DIVISION

COMPUTING SCIENCES

ANESTHESIOLOGICAL TRAINING SIMULATOR

A REPORT TO

UNIVERSITY OF SOUTHERN CALIFORNIA

PURCHASE ORDER 80051

REPORT NO. 3496 (FINAL) / FEBRUARY 1968 / COPY NO. 42

AEROJET
GENERAL TIRE
GENERAL

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

AEROJET
GENERAL TIRE
GENERAL

ANESTHESOLOGICAL TRAINING SIMULATOR

A. P. Clark and L. Taback

A Report To

UNIVERSITY OF SOUTHERN CALIFORNIA

Purchase Order 80051

Report No. 3496 (Final) February 1968

AEROJET-GENERAL CORPORATION
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

Report No. 3496

FOREWORD

The research reported herein was performed under a subcontract with the University of Southern California pursuant to a contract with the United States Department of Health, Education, and Welfare, Office of Education, under the provisions of the Cooperative Research Program.

This final report completes the fulfillment of work under the University of Southern California purchase order and covers the period from 1 January 1966 to 1 February 1968.

CONTENTS

Page

I. INTRODUCTION 1

II. TECHNICAL DISCUSSION 1

A. THE SYSTEM 1

1. Instructors's Console 2
2. Anesthesia Machine 3
3. Computer 3
4. Manikin 3
5. Interface 3

B. MODELING 4

C. SOFTWARE SYSTEM 7

1. Formulation of System 7
2. Program 8

D. SENSORS AND SPECIAL-PURPOSE HARDWARE 11

1. Drug Sensor 11
2. Airway Monitoring and Cuff Status 13
3. Anesthesia Machine 13
4. Heart-Sound Generator 14
5. Sphygmomanometer 15
6. Color-Change Mechanism 16

E. MANIKIN 17

1. Actuations 18
2. Actuation Details 19

CONTENTS (cont.)

Page

III. CONCLUSIONS ____ 24

IV. RECOMMENDATIONS ____ 26

Table

Instructor's Console, Display and Monitoring Functions ____ 1

Instructor's Control Inputs ____ 2

Figure

Simplified System Block Diagram ____ 1

System in Simulated Operating Room ____ 2

System Block Diagram ____ 3

Instructor's Console, Left-Hand Control Panel ____ 4

Instructor's Console, Right-Hand Control Panel ____ 5

Block Diagram of System Model ____ 6

Simulation of Drug Concentration ____ 7

Effect of CO_2 on Breathing Rate and Amplitude ____ 8

Program Flow Chart ____ 9

Typical Printout ____ 10

Disassembled Septum Holder ____ 11

Needle Sensor, Schematic ____ 12

Packaged Drug-Sensing Electronics ____ 13

Drug-Metering Mechanism ____ 14

Anesthesia Machine, Flowmeter Modifications ____ 15

Accessories for Modified Anesthesia Machine ____ 16

CONTENTS (cont.)

Figure

Y-Valve Sensor, Schematic 17
Heart-Sound Comparison, Oscilloscope Traces 18
Heart-Sound Generator, Schematic 19
Color Control, Schematic 20
Manikin, as Seen from Instructor's Console 21
Manikin, as Viewed by Student 22
Closeup of Manikin's Torso 23
Skull, Front View 24
View Showing Manikin's Skull with Skin in Place 25
Sculptured Plaster Model of Manikin 26
Plaster Model of Tongue, Larynx, and Lower Jaw 27
Exploded View, Tongue and Lower Jaw 28
Relay and Lamp Drivers, Schematic 29
Relay Driver 30
Skull, Rear View 31
Operating Table with Sides Removed, Showing Torso in Position 32

APPENDIX I - ANESTHESIOLOGICAL EQUATIONS

Figure

Time Constant for CO_2 Concentration as a Function of $\alpha = f(V_r, C)$ I-1
Functions for Breathing Rate and Amplitude I-2
Oxygen-Modifier Function I-3
Blood-Pressure Change as a Function of CO_2 Level I-4

CONTENTS (cont.)

APPENDIX II - SIGNIFICANT ANALOG RUNS

	Figures
Anoxia	1A & B
Asphyxia	2A & B
50-mg Injection of Pentothal	3A & B
200-mg Injection of Pentothal	4A & B
500-mg Injection of Pentothal	5A & B
40-mg Injection of Succinylcholine	6A & B
5-mg Injection of Vasopressor No. 1	7A & B
5-mg Injection of Vasopressor No. 2	8A & B
15% Cyclopropane	9A & B
200-mg Injection of Pentothal, then 80% N_2O	10A & B

APPENDIX III - MANIKIN RESPONSES

APPENDIX IV - PROGRAM LISTING

I. INTRODUCTION

This report describes work performed by Aerojet-General Corporation and its subcontractor, Sierra Engineering Company, on the design and fabrication of an engineering-feasibility model of a human patient for use in training students in manual skills involved in the anesthesia procedure of endotracheal intubation. The realistically simulated patient was instrumented and actuated to respond, under the control of a computer, to the many facets of this procedure.

In addition, Aerojet maintained and operated the simulator for the training experiment and demonstrations extending nominally from 1 July 1967 through 1 February 1968.

The engineering feasibility of the simulator was proven and the effort is considered highly successful. Investigators from the University of Southern California School of Medicine are preparing a report on the educational experiment.

II. TECHNICAL DISCUSSION

A. THE SYSTEM

The anesthesiological training simulator consists of five major components: the computer, the interface unit, the instructor's console, the anesthesia machine, and the manikin. Figure 1 schematically shows their interconnection as they are arranged to make up the simulator.

In broad terms, the instructor's console is used to monitor the ministrations of the student and the vital signs of the "patient," to control the modes of the simulator, and to insert trouble conditions to give the student experience in emergency procedures. The manikin is used to provide a realistic subject to which the student administers drugs and gases while he physically performs intubation and reads vital signs. Certain physiological phenomena are animated and controlled by signals from the computer. The computer serves as the sensing device for inputs from the system and as the reaction-signal-generation device for system control. The anesthesia machine acts as a gas-control and ventilation-pressure-control device through which the student administers gaseous agents; the sphygmomanometer readout is attached to this machine.

The interface unit contains power-amplification and signal-conditioning electronics to match the outputs of the various devices to their respective loadings. It is not a simple single unit (as indicated in Figure 1) but is distributed within the system and includes parts of the computer and some special electronic packages in both the instructor's console and the manikin.

The manikin is considered to include the simulated human body and the table upon which it reclines, as well as the electronic and electropneumatic actuators under the table. The computer, a hybrid, is considered to include the linkage system that provides communication between its analog and digital components. Figure 2 shows the simulator as it was used for training, and Figure 3 is a detailed block diagram of the system.

1. Instructor's Console

This unit provides both monitoring and control functions for the instructor. It allows him to control the mode of the simulator, monitor the student ministrations, and insert troubles as perturbations on the solution of the patient's physiological and pharmocological model.

Figures 4 and 5 show the control panels. Table 1 describes the monitoring functions and Table 2 the control functions.

The console also houses the ±15-volt power supplies, some of the interface electronics, and relays for use in controlling power to other units of the system.

2. Anesthesia Machine

This unit is an actual anesthesia machine (Ohio-Heidbrink Model B3303) modified as necessary to provide inputs to the computer and instructor's console for the monitoring of gas flows and the checking of connections. These modifications were made as unobtrusive as possible, to maintain a high degree of realism while providing the necessary signals.

The machine is used by the student to administer simulated anesthesia gases to the manikin. With a rebreathing bag, the student can artificially ventilate and aid the spontaneous breathing of the patient. The machine was used with no modification whenever possible. Details on the modifications are presented in Section II,D, below.

3. Computer

This unit consists of portions of Aerojet's general-purpose hybrid computer and includes an EAI 231R analog computer, a Computer Control Company DDP-24 digital computer with 4096 words of memory and a linkage system made up of a 20-channel multiplexer, an analog-to-digital converter, and 20 digital-to-analog converters, as well as miscellaneous logical elements. A real-time clock in the computer is the master timer for iterations of the computations and for control of the repetition rate of sensor-signal inputs.

4. Manikin

The manikin has a plastic body whose outer skin is constructed of polyurethane and polyvinyl over polyurethane foam and a skeletal structure of fiber glass and epoxy resin. The operating table on which the body rests contains (a) the electropneumatic actuators that control the articulations, (b) most of the sensors used to detect student inputs, and (c) the sound transducers for the heart and the brachial artery.

5. Interface

The interface unit consists of relay drivers, amplifiers, an encoder for coding switch inputs from the console for input to the computer, voltage comparators, and miscellaneous logic elements. These components are distributed throughout the system and serve mainly to provide power for lighting lamps, driving relays, or powering electropneumatic actuators. The are also used to linearize nonlinear sensor outputs for meter readout or to change the form of a sensor's output for input to a computer. Some of these elements are discussed in more detail in Section II,D.

B. MODELING

The system model is shown in block-diagram form in Figure 6. It resembles a complex feedback-control system involving the interaction of input parameters and physiological variables. No attempt was made to model the organs in the sense of duplicating their physiology or structure. As an example, heart action is not simulated by the motion of valves and blood flow in chambers as a result of electrical stimuli. Instead, a parameter of interest to an anesthesiologist (e.g., the pulse rate) is calculated as the output of a transfer function whose inputs are oxygen and carbon dioxide concentration, anesthesia level, etc., which in turn are functions of other variables that may depend on the pulse rate. The relationships between the variables were empirically derived on the basis of the literature and of information from experienced anesthesiologists. The critical criteria - i.e., the responses of a patient in various anesthesiological situations - were verified by the University of Southern California anesthesiologist in charge of the project.

Examples of the types of relationships and transfer functions are cited below

With regard to analysis of the distribution and effect of injectable drugs, it is known that after injection there is a time lapse before the drug begins to take effect. This amounts to a pure transport delay of approximately 20 sec, after which two mechanisms determine the anesthesiological effect: (1) distribution to the organs, and (2) elimination from the organs. In particular, the effect of the drug follows the concentration in the viscera. Figure 7 shows the visceral concentration after injection. It was found that by combining lag and lead transfer functions (Figures 7b and c) with properly selected time constants, this curve could be fitted within a few percentage points. The overall transfer function [H(s)] is given by

$$H(s) = \frac{sT_G T_L}{(sT_G + 1)(sT_L + 1)}$$

where s is the Laplacian operator. Dynamically, the time constants (T_G and T_L) are actually functions of other physiological parameters (e.g., the blood-circulation rate).

Similarly, the concentrations of O_2 and CO_2 in the blood are simulated by combinations of these simple transfer functions.

Figures 8a and b show the effect of the partial pressure of CO_2 (PCO_2) on breathing rate and amplitude. These curves plot the results of empirical data and by their nature cannot easily be expressed analytically. They are therefore stored as functional tables consisting of values for abscissas and corresponding ordinates. For any partial pressure of CO_2, the computer makes a linear interpolation between the stored values. Similarly, functional tables are stored for other nonanalytic relationships between variables, as well as for use in linearizing transducer outputs.

Portions of the model were originally formulated as analog problems, using only the analog computer, for the following reasons: (1) As a complex feedback system, stability conditions could be investigated more readily; (2) the coefficients of empirical equations could be changed and determined more rapidly; and (3) transfer-function analysis is more in the province of analog computers.

After the equations were generated and the coefficients evaluated, the system was reprogramed for the digital computer, because (1) that computer has a greater capability for handling complex logical relationships which are not computational in nature, especially switch inputs from the control console; (2) transport delays are more easily implemented; (3) the setup for operational runs is easier in that only a program tape need be loaded, whereas potentiometers and diode function generators must be set for an analog computer; and (4) for potential future production, a digital computer would have greater advantage over an analog computer with respect to cost, size, and flexibility of reprograming.

At present, approximately 90% of the simulation is by digital computer, with the entire 4096-word memory being utilized. The portion left to the analog computer involves the heart-sound and pulse generators, the fasciculation generator (which simulates muscular reaction to one of the drugs), and the use of amplifiers for level shifting and power amplification.

Empirical equations describing the relationships between inputs to the simulated patient and the output reactions are presented in Appendix I. They were implemented as an analog-computer simulation, and the results of various inputs were plotted on a strip-chart recorder as a function of time. This simulation was used to establish the final equations, which were implemented as a hybrid analog/digital-computer simulation. Some of the more significant runs are summarized in Appendix II. They include induced anoxia and asphyxia, injection of Pentothal (50, 200, and 500 mg), injection of succinylcholine (40 mg), injections of Vasopressors 1 and 2 (5 mg each), use of cyclopropane (15%), and injection of 200 mg of Pentothal followed by 80% N_2O.

The physiological and pharmacological responses of the manikin are controlled by computer-generated electrical signals. The signals are keyed mainly on (1) the concentration of succinylcholine, the vasopressor drugs, the anesthesia agents, and O_2 and CO_2 as calculated by the mathematical model; (2) various external physical stimuli in the form of student ministrations; and (3) perturbations introduced by the instructor through manipulation of his control console. These responses are described in detail in Appendix III.

C. SOFTWARE SYSTEM

1. Formulation of System

For a simulation involving human response to stimuli in a realistic teaching situation, the computer must operate in real time. Such operation is provided by a real-time clock with an interrupt feature.

Program flow is shown in Figure 9. Briefly, the operation is as follows:

After all parameters and conditions are set for program initiation, the clock is set to interrupt every 0.1 sec, and the interrupt feature is enabled. When interruption occurs, the computer samples (via the analog-to-digital converter) the external conditions that determine the status of the stimuli. These include (a) the needle sensor, (b) the volume of drug injected, (c) anesthesia-machine gas-flow transducer voltages, (d) lung-position sensors, and (e) the airway-position sensor.

The computer then checks the status of the mode switch on the control console; the switch includes three interlocked pushbuttons (a yellow "reset," a red "hold," and a green "operate" button). In the reset position all parameters are maintained in the normal condition. Time is also reset, and only the lung drive and eyelid tenseness are changed to simulate normal breathing and blinking. In the hold position, no computations are made that change the physiological variables. Student ministrations have no effect on the model, and time is held constant. In the operating position, the physiological variables are recalculated according to their current values and the changing input parameters, and time is advanced. The computer then generates, through the digital-to-analog converters, variables that actuate transducers on the manikin or set meters on the control console. These include (a) effective drug concentrations, (b) blood pressures, (c) effective oxygen level in the blood, (d) anesthesia level, (e) ventilation rate, (f) pulse rate, (g) jaw tension, (h) eyelid tension, (i) lung-position drive, (j) vocal-cord tension, and (k) anesthesia-gas flow rates linearized for the meters.

The computer then leaves the interrupt routine until the clock runs down and interrupts again, whereupon the process is repeated. The interrupt routine occupies approximately 33 millisec, which means that the computer is idle about two-thirds of the time. Human motor reactions are mostly at low frequencies, and it was found that updating the physiological variables every 0.1 sec was often enough to cause smooth responses. This known computation cycle is required to implement digital transfer functions involving time constants and transport delays operating in real time.

2. Program

The program was written in DAP symbolic language, with all routines in relocatable form. It consists of a monitor (MAST) that controls the operation of the real-time clock, determines which subroutines are to be performed, and sequences their operation. In general, each subroutine is made up of two parts: (a) initialization, which resets parameters, flags, counters, and memory blocks and is called when the control console is in the reset mode, and (b) a portion performed usually in the operating mode. Appendix IV provides a complete program listing.

The subroutines are of two types: (a) special ones that make calculations for a physiological system, and (b) utility routines of a more general nature that perform some mathematical or logical function and may be used by other programs. They are described briefly below; their names are the symbolic ones used in the calling sequence.

a. Special Subroutines

(1) The NEDL routine handles the input of injectable drugs and provides for up to ten different ones as determined by the magnetic properties of the needle used for injection. It determines which drug is injected and the amount injected, and then lights the appropriate lamp on the console. The cumulative dose for each drug is calculated for storage in memory "delay lines," to become effective a predetermined time

later. The routine also controls a valve that allows the injected liquid to be discharged from the chamber that measures the size of the dose.

(2) The DRUG routine handles the output from NEDL. Given the delayed cumulative dose as input, the effective or visceral concentrations of the injectable drugs are computed in accordance with their appropriate transfer functions. The effective anesthesia level is also calculated.

(3) The CIRC routine calculates the circulation rate, the pulse rate, and the systolic and diastolic blood pressures. The input parameters that affect these calculations are the manual switch inputs, O_2 and CO_2 concentrations, drug injections, and anesthesia level.

(4) The RESP routine computes the ventilation rate as determined by the lung-position sensors, breathing rate, breathing amplitude, and effective concentration of O_2, CO_2, and the gases from the anesthesia machine. It also generates the lung-drive signal.

(5) The ACTS routine determines the status of the variables transmitted to the transducers in the manikin to produce mechanical motions. The variables may be continuous (pupil dilation, jaw tension, vocal-cord tension, etc.) or discrete signals, usually output control pulses, producing arrhythmia, bucking, and fasciculation, for example. Inputs to ACTS include the console-status word and the physiological variables calculated in the previously described routines.

(6) The two-section PRIN routine types a time history of significant events during a run (Figure 10). The first section, called whenever an event occurs, causes the time of occurrence and a code for that event to be stored sequentially in a print-storage memory block. After the run, the second part of PRIN picks up each entry in the block, decodes it, and types it in the required format.

b. Utility Subroutines

(1) The ANIO is a general input-output routine for communication with the analog computer. Its input parameters are the first

address of the block of memory cells to be input or output, the first address of a block of constants that scale the input or output voltages, the determination of whether input or output is to be performed, and the first and last digital-to-analog (D-A) or analog-to-digital (A-D) channels to be used. The transfers may be made optionally without scaling.

(2) When called at a fixed interval, the LEAD routine iteratively implements a transfer function of the form

$$\frac{e_o}{e_i} = \frac{s}{sT_L + 1}$$

where e_o is the output and e_i is the input.

The equations solved are

$$e_o = e_i - \overset{o}{e}_L$$

and

$$\overset{1}{e}_L = \overset{o}{e}_L + e_o \left(\frac{\Delta T}{T_L} \right)$$

where $\overset{o}{e}_L$ is the value of a storage cell from the previous iteration, $\overset{1}{e}_L$ is the new value of the storage cell, ΔT is the time interval, and T_L is the time constant.

(3) When called at a fixed interval, the LAG routine iteratively implements a transfer function of the form

$$\frac{e_o}{e_i} = \frac{1}{sT_G + 1}$$

The equation solved is

$$\overset{1}{e}_o = \overset{o}{e}_o + (e_i - \overset{o}{e}_o) \left(\frac{\Delta T}{T_G} \right)$$

where e_o^1 is the new value of the output, $\overset{o}{e}_o$ is the value of the output from the previous iteration, e_i is the input, and T_G is the time constant.

(4) Given an arbitrary function of Y = f(X), which is stored as discrete values of X and Y, the FUBR routine determines the value of Y for any value of X within the range of X defined in the table of values. The routine performs linear interpolation between points. The inputs are the value of the independent variable (X) and the first address at which the table is stored in memory. The first table entry contains the number of points stored.

(5) The DLAY routine, when called at a fixed interval, implements a transport delay. It accepts an input, stores the input in a memory delay line, and outputs the input that occurred a predetermined time previously. The values of the inputs are not changed by the DLAY routine.

D. SENSORS AND SPECIAL-PURPOSE HARDWARE

1. Drug Sensor

The drug-sensing mechanism is required (a) to identify the drug being injected, and (b) to measure the amount injected. In order to maintain the realism of the simulation, all designs involving external wires or appendages were discarded. The final design for drug identification consists of a small coil embedded in a plastic septum holder. The two wires needed for electrical connection are routed through the catheter that also carries the injected fluid. Figure 11 shows the disassembled septum holder, which consists of the main body housing the small coil, replaceable silicone-rubber disks through which the fluid is injected, and a screw-on cap to hold the rubber disks in place. (The figure includes a 1/2-in.-square marker to indicate scale.)

The coil forms half of a tuned circuit operating in the vicinity of 100 kc. Figure 12 shows the electronic circuitry. Coded needles, containing different amounts of ferromagnetic material, are used for the different drugs. As a needle is inserted through the rubber septums, and thereby through the coil, the tuned circuit is electrically loaded in proportion to the amount of ferromagnetic material. The electronics thus generate a voltage whose magnitude identifies the needle. The final packaged electronic unit is shown in Figure 13.

With the drug (i.e., needle) identified, it remains only to meter the injected dose by the mechanism shown in Figure 14. The fluid being injected displaces a double-acting stainless steel piston. A linear-motion potentiometer, directly driven by the piston, provides an electrical signal proportional to the volume injected. After each injection, this fluid is exhausted through valving. The control portion of the mechanism consists of an electrical valve actuator, a pilot relay, a pilot actuator, two valves, and an electrical limit stop consisting of a microswitch and an actuator.

The control system operates as follows: When a needle is inserted into the drug-identification unit, a signal is generated to energize the pilot relay, which in turn energizes the valve-actuating solenoid. This causes Valve A to disconnect from the pneumatic pressure that would normally return the piston to its zero position and also de-energizes the pneumatic actuator. Valve B, when de-energized, connects the catheter to the input side of the cylinder and disconnects the exhaust line. In this condition the injected fluid displaces the piston, thus quantifying the injection. When the needle is withdrawn, Valves A and B are actuated. Valve A pressurizes the cylinder, causing it to return, while Valve B connects the exhaust line to the cylinder to permit the injected fluid to be dumped. An electrical limit stop is actuated at the zero position of the piston to de-energize the electrical valve actuator to avoid keeping the system pressurized. A small adjustable orifice is used in the pneumatic pressure line to permit selection of the cylinder-return rate.

Flourochemical FC 75 of the Minnesota Mining and Manufacturing Company was used initially for the drug material, because it is extremely inert and would not cause adverse electrical or chemical effects. The mechanism, however, was found to be extremely reliable with distilled water, which was used throughout the program for reasons of economy.

2. Airway Monitoring and Cuff Status

The position of the airway in the trachea is monitored by a scheme similar to that used to identify drugs. The electronics are identical. A coil was wound and placed within the aryepiglottic-fold actuator, which is molded in the shape of a doughnut and through which the trachea extends. The endotracheal airway is fitted throughout its length with a number of thin steel wires held in place by a thin, inner, vinyl tube. The wires were cut in successively diminishing length (each approximately 1/4 in. shorter than the preceding one). The completed bundle thus approximates a flexible steel strip that tapers from one end of the airway to the other. The exact lengths were adjusted to obtain an electrical signal that varied linearly with the depth of airway insertion. For improved sensitivity in detecting the proximity of the airway tip to the aryepiglottic folds, the tip was fitted with an extra piece of metal; this does not affect the measurement of insertion depth after the tip has passed through the coil.

A number of designs for the detection of airway-cuff status were implemented and tried. The early ones, using mechanical switches actuated by cuff pressure, were unreliable in that flexure at the neck and trachea during intubation would cause actuations. A device employing a conductive fluid, with two electrodes for use in measuring its resistance, was built and satisfactorily laboratory-tested, but permanent crimping of the tube occurred at installation and poor accessability made it inadvisable to attempt a correction. Minor modifications were made in the digital program to compensate for the cuff-sensor failure.

3. Anesthesia Machine

A standard anesthesia machine was modified for this program. The fittings were changed to permit the use of (a) compressed air for oxygen, and (b) carbon dioxide for nitrous oxide and cyclopropane. These substitutes are readily available and easy to handle. Because they closely approximate the densities of anesthesia gases, this choice did not seriously affect the calibration of the flowmeters in the anesthesia machine.

Flowmeters for remote sensing were implemented by replacing the plugs, normally on top of each flowmeter in the Ohio-Heidbrink machine, with small calibrated orifices. Each orifice is between the output of the float-type flowmeter and the manifold that collects all the gases before they exit to the breathing bag. Two pressure taps, on opposite sides of the orifice, are led off to a differential-pressure gage. Because the pressure drop across the orifice is related to flow, this instrument may be used to monitor gas flow remotely. Figure 15 shows the orifices. An aluminum cover (not shown) is used to hide this modification from the students, and the entire installation looks like a slight extension of the standard machine.

A Y-valve modification was required to permit remote indication of mask or airway connection to the anesthesia machine. This was done by providing two coaxial split commutators at the connection end of the valve. The inner pair are connected when the airway is inserted, and the outer pair when the face mask is connected. To provide a continuous electrical connection, the face mask was fitted with a machined aluminum ring in place of the normal rubber ring. The wires from the commutator sections to the electronics were run through the anesthesia-machine hosing. Figure 16 shows the modified mask, airway, Y-valve, and electronic-sensing package, and Figure 17 shows the electronic package schematically.

In addition to the metal ring, the face mask was fitted with magnets in the inflatable pad. Their purpose is to activate the reed relays embedded in the manikin's face when the mask is properly placed.

4. Heart-Sound Generator

The heart-sound generator was implemented with general-purpose computing elements on the analog portion of the hybrid computer. The heart rate is determined by a sync generator whose frequency is determined by its input voltage. The envelope of the first heart sound is generated by a triangular-wave generator driven from the sync circuit. A second sync pulse derived from the first sound generator is appropriately delayed and initiates the operation of a second triangular-wave generator, producing the envelope of the second heart sound. The first and second sound signals are summed and are used to modulate a 75-cps signal. Figure 18 shows the resulting signal and a normal heart-sound signal obtained from a teaching tape. Figure 19 shows the circuit implemented on the computer.

Arrhythmias are obtained by switching a 0.5-cps signal into the sync-generation portion of the system to cause extra and missing beats. The arrhythmias may be switched in manually from the console, by the instructor, or automatically by the computer as a function of the CO_2 level in the blood. The signal is transmitted to a sound transducer under the manikin. The transducer output then proceeds to the student's headset, via plastic tubing that passes through a simulated stethoscope taped to the manikin's chest. A second transducer generates appropriate pulse sounds from a signal derived from the sync signals in the heart-sound generator and directs them through a simulated stethoscope taped to the manikin's arm at the brachial artery. The student may select either sound source by means of a small valve, exactly in the same way as in surgery. Additional circuitry is used in the heart-sound generator to modulate the sound intensity as a function of blood pressure and cuff pressure.

5. Sphygmomanometer

The sphygmomanometer mechanism consists of a standard wraparound pressure cuff, the bulb, a pressure-to-electrical-output transducer, a voltmeter, a sound transducer, a simulated stethoscope head, and the computer. The cuff is wrapped around the left arm of the manikin and can be inflated in the normal manner by the student. The simulated stethoscope head is strapped to the inner portion of the elbow and covers the hole through which a vinyl tube leaves the arm. The tube transmits the brachial-artery sound from the transducer beneath the table to a three-way stopcock, which allows the student to switch his earpiece between this stethoscope and a second head, taped to the manikin's chest, through which heart sounds are transmitted. The cuff pressure is sensed by the pressure transducer in the table. The transducer generates a voltage proportional to the cuff pressure that is read by the computer and sent to the voltmeter on the anesthesia machine, which is calibrated in pressure (mm Hg). The student reads the cuff pressure from the meter. This value is compared by the computer; if the cuff pressure is between the computed systolic and diastolic pressures, the computer generates a voltage level that operates a relay to allow the brachial-artery sounds to be generated by the sound transducer. In addition, the relay allows a "pulse tic" to be added in synchronism with the sound to the voltmeter, giving a realistic appearance to the sphygmomanometer meter.

6. Color-Change Mechanism

Figure 20 schematically shows the voltage control of the manikin's-color-change mechanism (involving red and blue lights) that was abandoned because skin opacity made the scheme unusable. The circuit was built and checked out with an equivalent load and worked well. As designed, a color signal (red or blue) is generated as two continuous variables by the computer, varying according to the level of oxygen in the blood. The red-lamp control voltage is increased from zero as the simulated patient becomes hyperoxygenated, and the blue-lamp control voltage increases from zero as he becomes critically cyanotic.

The major element in the circuit is a silicon voltage-controlled rectifier (SCR). With voltage increases, more of the conducting half-cycle of the alternating voltage applied to the transformer is allowed to pass through the SCR and is then filtered, essentially raising the average d-c voltage to the lamp load and hence the intensity of the light.

Other schemes were considered to accomplish color change, but were not used for various reasons. They included the use of

a. Photochromic paint, which changes hue under the influence of ultraviolet light and returns to its original color on removal of the stimulus. The paint, however, requires too long (about an hour) to return to the original color.

b. Electroluminescence, employing a plastic strip that glows on the application of voltage. Such strips are available in several colors, but glowed too dimly for the skin opacity.

c. Fluid methods. Aerojet experimented with two potential approaches employing fluid and dyes. One involved the use of blue and red fluids in individual reservoirs connected to either end of a spiral of vinyl tubing. The colors were separated by a slug of mercury; pressurization of the red or the blue reservoir forced the desired fluid into the spiral to change the color of the area it covered.

The second approach investigated was the use of a large bladder with a continuous supply of fluid flowing through it. When color changes were desired, a dye would automatically be added, mixed with the fluid in a mixing chamber, and allowed to fill the bladder.

Both methods have promise, but are countered by skin opacity. Color distribution also presents problems, because the areas that undergo pronounced changes are small and thin (lips, cheeks, ear lobes, etc.).

d. Fiber optics to transmit light to certain areas. These were considered but not used, due to lack of time and engineering difficulties.

E. MANIKIN

The manikin represents a human male about 6 ft in height and weighing approximately 200 lb (Figures 21 and 22). Fabricated under subcontract by Sierra Engineering Company of Sierra Madre, California, its body is constructed of polyurethane skin over polyurethane-foam "flesh." The fiber-glass and epoxy rib cage (Figure 23) is slotted to provide the required elasticity during respiration. The head consists of a low-temperature-meltable polyvinyl skin over a glass and epoxy skull (Figures 24 and 25). The mandible is hinged to allow the mouth to open and close realistically.

The skin was fabricated by casting the plastic in a room-temperature-vulcanizing mold formed from a sculptured plaster model of the head and upper torso (Figure 26). The oral cavity (Figures 27 and 28) was cast from a sculptured model obtained by taking a casting of a cadaver. It was made of polyvinyl plastic and was fitted to form an airtight seal to the skin to allow artificial, positive-pressure ventilation with a face mask and anesthesia machine. The teeth were fabricated by the Dental School of the University of Southern California and are of the same material as artificial dentures. The trachea and the opening of the esophagus are of polyvinyl plastic and provide air passages to the lungs and abdomen. The trachea is fabricated to appear realistic down to the vocal cords and includes the aryepiglottic folds.

1. Actuations

Various simulated muscles are actuated to provide realistic-appearing movements of certain areas of the body. The actuations include the

Eyelids and forehead
Pupils of the eye
Jaw
Vocal cords
Aryepiglottic folds
Lobes of the lung
Abdomen
Shoulder area
Temporal and carotid pulses
Torso (for bucking)
Vomiting mechanism
Epiglottis.

Most of the actuators are electropneumatic and employ power from a compressed-air supply regulated by solenoids or pressure transducers and working into pistons, rolling diaphragms, bellows, or inflatable bladders.

In the case of continually controllable actuators, such as that operating the jaw, a continuous computer signal is generated whose amplitude is proportional to the required degree of motion. In the case of actions of the on-off type, such as vomiting, the computer generates a potential of either 5 volts or zero to actuate the solenoids through relay drivers. Figure 29 shows the relay driver schematically, and Figure 30 shows the electronic package. When bucking is to be initiated, the computer produces a continuous train of on-off pulses.

Figure 31 shows two of the rolling-diaphragm-type actuators within the skull; one actuates the eyelids and the other dilates or constricts the pupils. Figure 32 shows some of the electropneumatic mechanisms used to control the lungs and abdomen, as well as transducers for actuators contained in the body and head.

An attempt to achieve color change as a cue to the level of blood oxygenation was made by inserting blue and red light bulbs beneath the skin in the temporal area and the chest cavity. The skin thickness and opacity made this approach unsatisfactory, and the scheme was abandoned.

The color of the body was originally attained by the use of aniline dyes on the polyurethane of the torso and arms. This produced very realistic coloration, but the dye proved unstable and soon turned yellow. Because the reason for this instability could not be determined, skin color was achieved by means of urethene paint on the body and vinyl paint on the head. The paint was not as realistic as the dye to touch or sight, but provided a satisfactory solution and did not detract appreciably from the training mission.

2. Actuation Details

a. Eyelids

The eyelids are of a shutter type (doll's eyelids); they are mounted on dual shafts and driven by a rolling-diaphragm actuator through two springs. The force on them is directly proportional to the air pressure acting on the rolling diaphragm. The spring drive allows either lid to be opened manually without affecting the other. The forehead wrinkle is also connected to this actuator so that the brow appears to "squint down" for tightly closed eyelids. The pressure to the rolling-diaphragm actuator is controlled by an electrical-to-pressure (E/P) transducer whose air-pressure output is proportional to the amplitude of the applied voltage. This actuator is located within the skull.

b. Pupil Dilation

The pupils consist of black rubber cones forced against flats within the hollow, hemispherical "eyeballs." As the cone is pushed against this flat by a push rod activated by a rolling-diaphragm actuator in the skull, the tip of the rubber cone spreads out and forces an opaque colored fluid away from the clear front of the eye, causing the appearance of dilation. When the cone is withdrawn, the fluid flows back in as the rubber contracts, and the pupils appear to contract. Again, the pressure into the rolling-diaphragm actuator controls the force of the cone against the flat, and the pressure is in turn controlled by an E/P transducer under the table.

c. Jaw

The jaw actuator consists of a lever and piston that operate the mandible around a spring-loaded sliding hinge in the skull. The piston operates against the spring action of the jaw, which was cast to be normally open. As the pressure on the piston is increased by means of an E/P transducer, the jaw closes more and more tightly.

The unit was originally located under the table, and the force was transmitted to the jaw lever by a push-pull control cable, with a physical spring used to restrain jaw closure. This scheme proved to have excessive friction and restrained jaw opening. The head skin was therefore recast with the jaw open, the spring was removed, and the unit was moved into the head to eliminate the control cable. The jaw is still not as slack as desired under conditions of zero tension; future models should therefore be designed to allow a force pickup for a power boost on the jaw actuation. The amount of power boost would be made a function of jaw slackness.

d. Vocal Cords

The vocal cords consist of a preformed indentation in the lower end of the trachea. An inflatable bladder in the form of a toroid (doughnut) fits around this area and is constrained to expand only toward the center. As pressure in the bladder is increased, the central hole becomes smaller and forces the vocal cords to close. The pressure is varied by an E/P transducer. The bladder is located in the neck of the manikin and the transducer under the table.

e. Aryepiglottic Folds

This unit is similar to the vocal-cord actuator except that it is located around the top of the trachea and activates the preformed aryepiglottic folds. The major difference exists in the pressure control, in that this unit consists of a solenoid and the folds are either full open or full closed (depending on the state of the solenoid). The mechanism is located in the neck and the solenoid is under the table.

f. Lungs

The lung drivers consists of two servo-controlled actuators driven by E/P transducers. Each servo consists of a rolling-diaphragm actuator, a linear-motion potentiometer to measure the motion of the lungs, an E/P transducer, a summing amplifier to measure and amplify the difference between computed and actual lung position and to provide drive to the E/P transducer, a pressure-to-voltage transducer to measure the pressure buildup in the lung, and a switching device to freeze the drive to the E/P transducer upon receipt of block signals from the instructor's console.

A pressure switch in the lung is set to initiate pressure buildup in the lung bellows; in logical combination with an inhale/exhale signal from the computer, it generates an out-of-phase aided-ventilation indication on the console. One of the servos drives the two right lobes of the lung; the other drives the left lobe, which is represented by a single bellows unit.

The actuators generate a force on a lever connected through a crank that drives a bellows unit, forcing air into and out of the lungs. This crank also provides power to another set of levers, which cause the rib cage to move up and down in simulated breathing. The pressure transducer in the lung allows for aided or artificial ventilation by positive pressure from the anesthesia machine. It acts as a second input to the servo amplifier, and its gain is adjusted to give a realistic sensation to the student when he uses the rebreathing bag of the anesthesia machine to aid or perform ventilation.

As delivered by the subcontractor, the unit had all three lobes operating against the adjustable springs, and no feedback system was employed. This approach proved unsatisfactory, because of uneven lung motion and the unrealistic amount of pressure necessary from the rebreathing bag to ventilate the patient. Aerojet therefore modified the lungs to include the servos, and the performance has been very satisfactory. Except for the push rods and cranks that operate the chest, this unit is located under the table.

g. Abdomen

The abdomen is controlled by a rolling-diaphragm actuator driven by an E/P transducer whose force is proportional to the amount of pressure generated. This force operates on a lever that works against a spring and a crank shaft. The shaft has another lever that is attached to bellows, push rods, and a cam that pushes against the abdomen, causing it to move up and down realistically as in breathing. The bellows are capable of being inflated through the esophageal opening of the oral cavity; when pressurized, they operate the lever-crank mechanism and cause the abdomen to move up and down.

As originally received from the subcontractor, this unit was driven as part of the lung-actuator mechanism; however, it was separated from that mechanism when Aerojet modified the unit to include the servos, and is now driven by its own E/P transducer. Except for the push rod and abdomen crank, the unit is located under the table.

h. Shoulder-Muscle Area

This area is actuated to simulate muscle fasciculation as a result of succinylcholine injections. The unit consists of a solenoid-actuated valve that drives an inflatable bladder located between the rib cage and the outer skin of the shoulder. As the solenoid is actuated, pressure increases and decreases in the bladder, which expands and contracts, causing the skin to move up and down in a reasonably realistic simulation of fasciculation. The solenoid is located under the table, and the bladder is in the shoulder area.

i. Temple and Carotid Pulses

The unit that produces pulsation of the temple and carotid arteries incorporates an E/P transducer located under the table. When actuated, this transducer pressurizes closed-end vinyl tubing in the temple and carotid-artery area, producing a pulsing sensation on each cycle of the signal.

j. Bucking

The torso is activated by two pistons pressurized through solenoids. When actuated, they force the torso to move upward an inch or so off the table in what closely resembles bucking. The torso is mounted on an aluminum box frame to which is attached actuating rods connected to the pistons. Weight and elasticity cause the body to return to the normal position when the pistons are depressurized. The pistons and solenoids are located under the table, and the push rod and frame are in the torso.

k. Vomiting Mechanism

The vomiting mechanism includes a solenoid valve that allows pressure to build up in a bottle containing a colored liquid. This pressure forces the liquid up a tube, which escapes near the back of the oral cavity and empties into the mouth. The solenoid valve and bottle are located under the table.

1. Epiglottis

A spring-loaded, formed lever at the base of the tongue is fitted into the vinyl epiglottis. It is actuated by pressure on the tongue from the tip of the laryngoscope blade, which causes the epiglottis to fold forward over the tip of the blade. This action is entirely manual; there are no powered devices.

III. CONCLUSIONS

The conclusions that follow are based on experience gained in designing, building, and operating the simulator and observation of the instructor and student doctors.

A. The program demonstrated the feasibility of building a computer-controlled patient simulator to a high degree of fidelity that appears to be useful in teaching certain manual skills in the medical/health-care fields.

B. The success of this first demonstration model suggests the desirability of other simulators to train similar manual skills and increases confidence in their success.

C. The simulator is a useful device to reduce potential discomfort for live patients while students perfect their manual skills in early stages of training.

D. The use of a simulator introduces students to various emergency procedures, in reaction to problems inserted from the instructor's console, that may be encountered rarely with live patients and involve danger to the patient when they are encountered. A student may complete his residency without ever employing certain emergency procedures on a live patient.

E. Observation during teaching sessions showed that the student could become as completely involved in the simulated situation as he would in an actual operation. Student comments indicated a high degree of acceptance of the device as a useful teaching tool.

F. After the initial setup the simulator was operated by medical personnel only, with engineering assistance available in the event of failures. This experience indicated that a doctor or other educator would have little trouble learning the operating procedures. Future models utilizing hard-wired, special-purpose, analog equipment and digital-computer equipment could be set up for training by a person relatively inexperienced in electronics or engineering (e.g., a doctor).

G. The use of an empirical-transfer-function description of the physiology and pharmacology turned out to be entirely adequate, and considerably reduced the required computer capabilities as compared with an explicit one-to-one mathematical model.

H. Some phenomena were observed that were not specifically modeled into the transfer functions (e.g., a condition resembling Cheyne-Stokes breathing), suggesting that simulation might lead to useful insights into their causes. It may therefore be useful to investigate the use of generative models, which relate output response to input stimulation without exact modeling, for other biological-medical fields of endeavor.

I. It was found that a high degree of reliability can be maintained despite the use of diverse mechanisms (plastic, mechanical, pneumatic, and electrical mechanisms, in addition to solid-state and vacuum-tube computers).

J. A simulator can be developed for delivery to a medical teaching institution that incorporates a computer of modest size, price, and capability. A computer that approximates the size of the household automatic clothes washer was investigated and found to be more than adquate. Advances in the integrated-circuit digital-computer field have made even smaller computers available; e.g., a device 10-1/2 in. high, 19 in. wide, and 15 in. deep, weighing 35 lb, has recently been introduced and could probably handle the digital-computer requirements for an identical, field-delivered simulator.

K. The anesthesiological training simulator could be used to provide quick training of doctors in emergencies or to introduce military medics or corpsmen to this skill to assist surgeons in emergency battlefield situations. Such training could be extended with reasonable validity to many areas of medical and health-care specialization.

L. A series of various simulators could also be used to eliminate candidates for a specialty whose requirements for coordination, physical dexterity, or strength would limit their potential success and to indicate fields more in keeping with their abilities.

No conclusions regarding the efficiency of this device as a teaching tool are presented here. These will be made by the University of Southern California educational experimenters.

IV. RECOMMENDATIONS

The success of this feasibility model leads to the following recommendations:

A. A deliverable model should be funded and built for use in a medical institution or several such institutions.

B. It is desirable to investigate the use of simulators for introducing new manual techniques in various specialties to practising doctors as aids in their continuing education, or for use as refresher devices.

C. To reduce the initial investment, it is recommended that consideration be given to the use of a van-mounted simulator that could be transported between several institutions for certain programed phases of instruction.

D. A team of medical and engineering investigators should undertake a detailed study to determine which medical and health-care training areas would be enhanced by the use of simulators. The study should include such factors as patient danger or discomfort, training cost-effectiveness, and training efficiency. Consideration should also be given to the use of simulator/trainers in meeting increased future demands for trained personnel.

TABLE 1

DISPLAY AND MONITORING FUNCTIONS, INSTRUCTOR'S CONSOLE

Parameter	Type of Display	Description
Drug monitoring		
Type	Lighted selector switch	A lighted switch for each of up to ten drugs. During injection, the lighting of a specific lamp identifies the drug being used.
Effective intravenous concentrations in manikin	Meter with lighted selector switch	Meter displays drug concentration in the viscera. Type of drug is established by a selector switch.
Dosage	Meter	Meter shows injected amount of drug presently being administered.
Blood pressure		
Systolic	Meter	Continuously displays systolic blood pressure.
Diastolic	Meter	Continuously displays diastolic blood pressure.
Oxygen level	Meter	Continuously displays effective oxygen level (vol%) in manikin.
Anesthesia level	Meter	Continuously displays computed level of anesthesia.
Anesthesia-machine flow rates	Four meters	Continuously displays flow rates of oxygen, nitrous oxide, cyclopropane, and other volatile agents such as Fluothane or ether.
Airway status		
Position	Meter	Shows depth of insertion of airway in trachea-bronchus system.
Mask connected	Lamp	Lights when face mask is properly connected to anesthesia machine.
Mask seated	Lamp	Lights when face mask is properly in place on manikin's face.

(cont.)

TABLE 1 (cont.)

Parameter	Type of Display	Description
Airway connector	Lamp	Lights when airway is properly connected to anesthesia machine.
Anesthesia gas	Lamp	Lights when mask is connected and properly seated or when airway is connected and inserted. Indicates the change from normal air to anesthesia-machine gases.
Respiratory rate	Meter	Shows respiration rate in liters per minute.
Heart rate	Meter	Shows heart rate in beats per minute.
Out-of-phase aided ventilation	Lamp	Lights when patient tries to exhale against excessive pressure from anesthesia machine.
Lip pinched	Lamp	Lights when excessive pressure is applied against lower lip.
Heart arrest	Lamp	Light when heart-fibrillate or heart-arrest switches are actuated.
Brochus blocks	Two lamps	Lights when bronchus-block switches (right or left) are actuated.
Audio headset jack	--	Allows instructor to listen to heartbeat.

TABLE 2

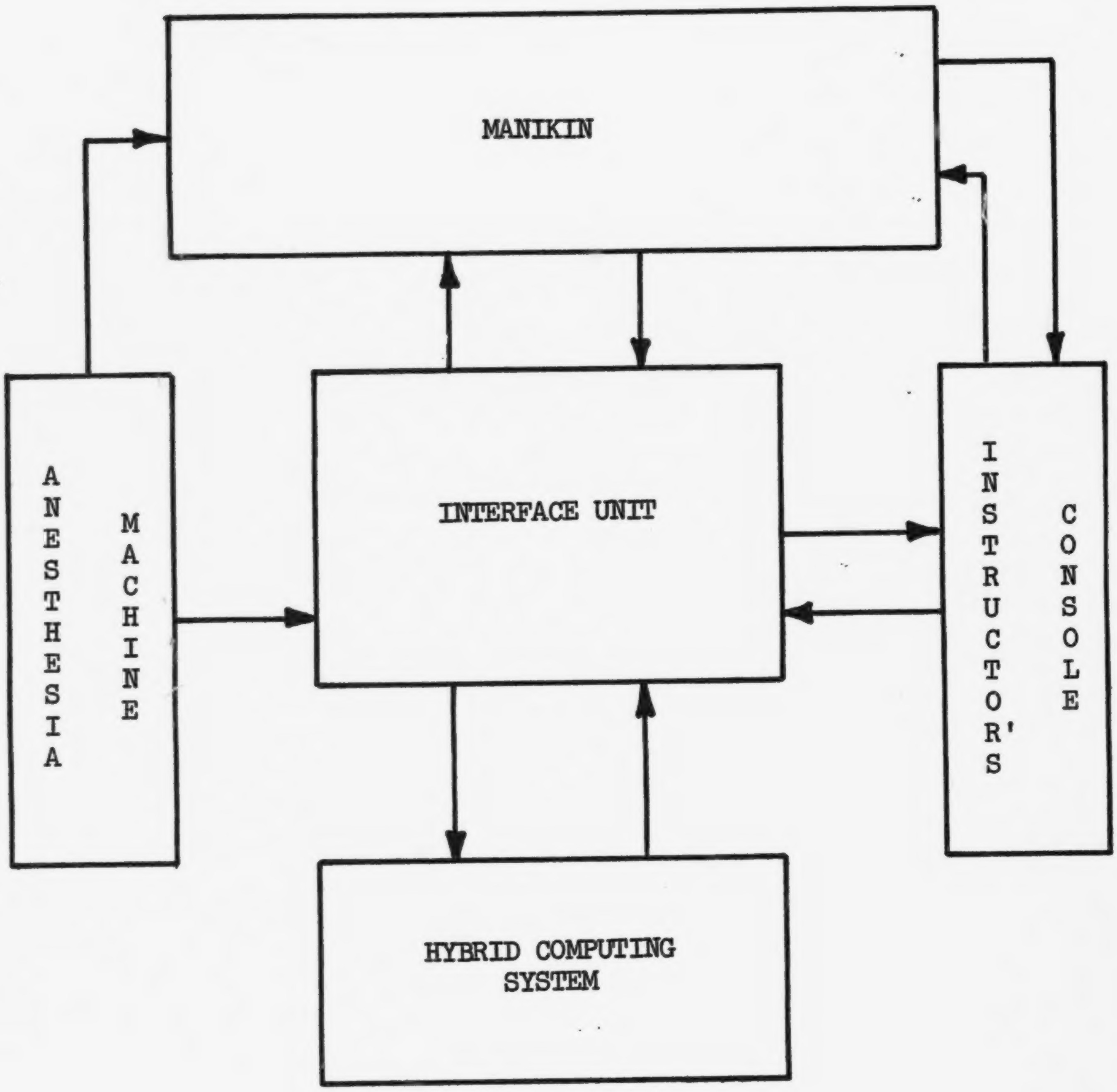
INSTRUCTOR'S CONTROL INPUTS

Parameter	Type of Control	Description
Blood pressure	Incremental increase or decrease	Momentary, three-position, center-off switch allows instructor to influence parameter as computed from mathematical model.
Pulse rate (heart rate)	Same	Same
Respiratory rate	Same	Same
Vomiting	On-off	Two-position switch, spring return to off, continues until empty or released.
Bucking	On-neutral-off	Three-position switch: Momentary on initiates action, momentary off stops action, and center position is neutral. In neutral position, computer can stop action under proper response from student.
Fibrillation	On-off	Two-position switch: Action (in this case, heart fibrillation) initiates and continues when on, and stops when off.
Arrhythmia	On-off	Same as fibrillation
Heart arrest	On-off	Same as fibrillation
Jaw tension	Incremental increase or decrease	Same as blood pressure
Bronchus block (right and left)	On-off	Same as fibrillation
Laryngospasm	On-neutral-off	Same as bucking
Simulator mode	Pushbutton switch	Three-position switch: Position 1 resets equations of simulator to initial condition, and manikin and student inputs are not accepted by computer. Position 2 holds or "freezes" time-dependent functions in the mathematical model, and inputs are not accepted. Position 3 sets the simulator to operate and time-varying parameters proceed as a function of time; inputs are accepted by the computer and change the outputs that result from the mathematical model.

(cont.)

TABLE 2 (cont.)

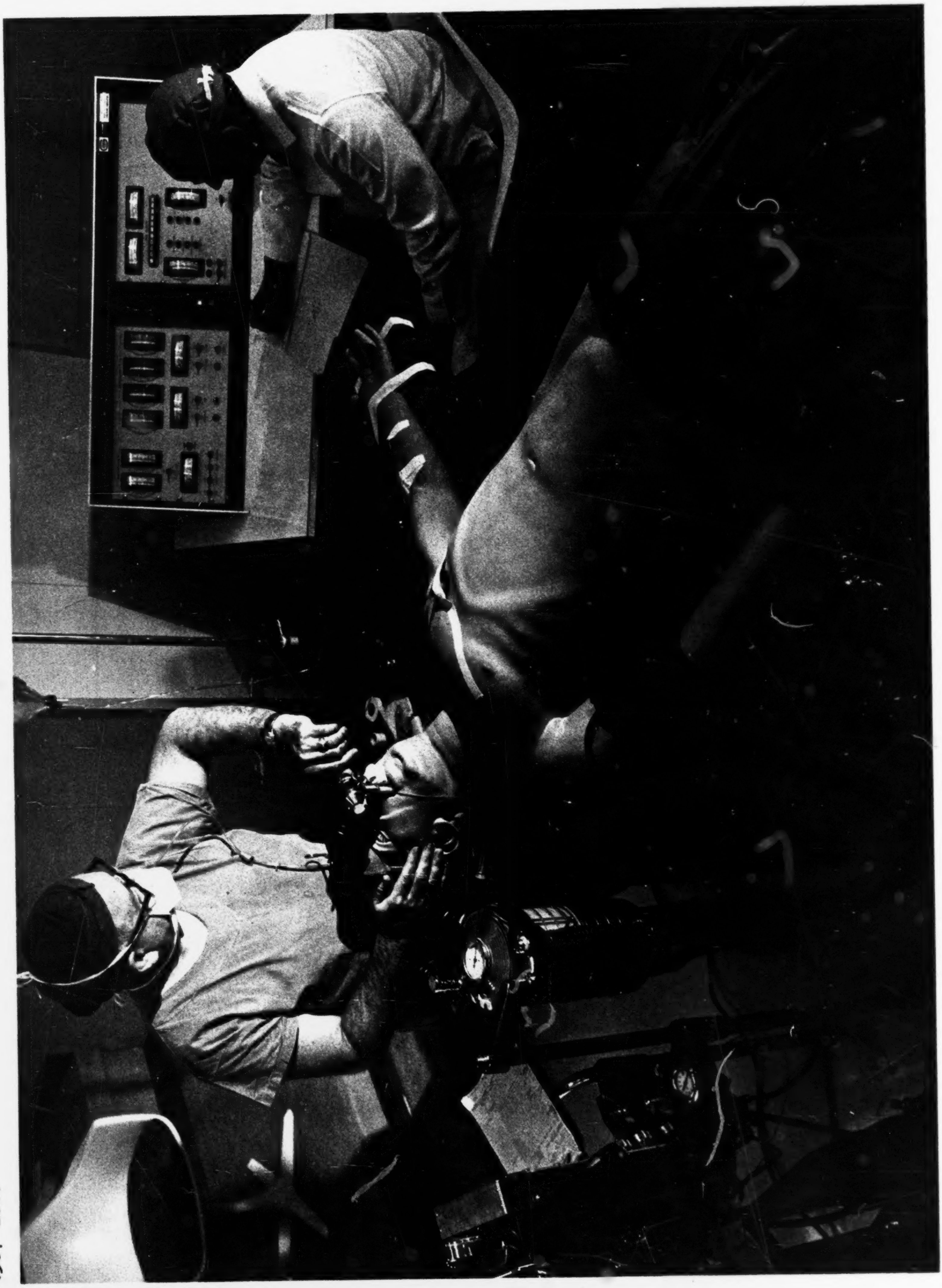
Parameter	Type of Control	Description
Print button	Lighted pushbutton	Momentary pushbutton: May be actuated during reset or hold modes of the simulator. Causes computer to print out data on significant events since the operate mode was last actuated. Button is lighted during printout, and the mode-change switch is disabled for this duration.


MANIKIN
ANESTHESIA MACHINE
INTERFACE UNIT
INSTRUCTOR'S CONSOLE
HYBRID COMPUTING SYSTEM

Simplified System Block Diagram

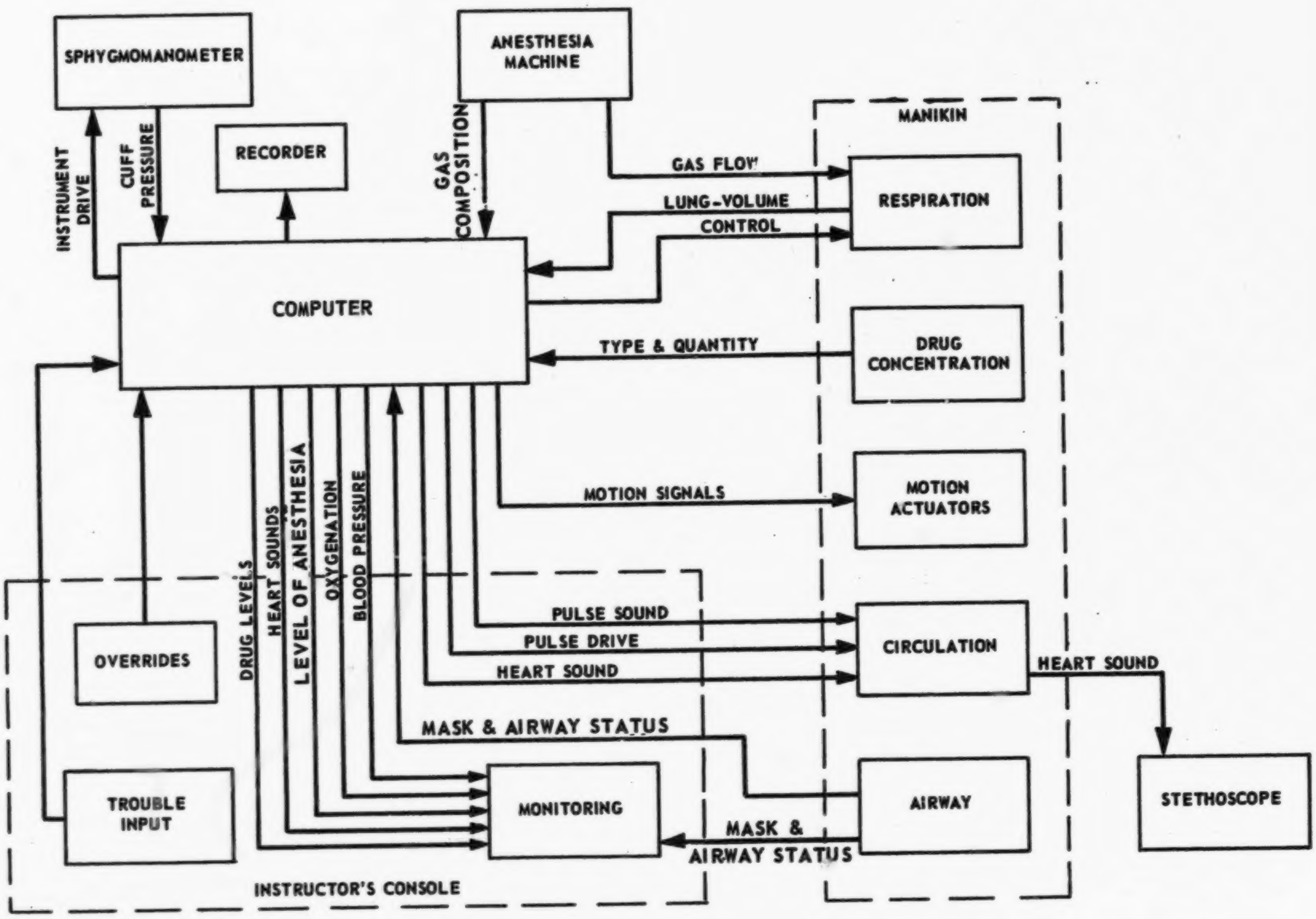
Figure 1

(367-166)



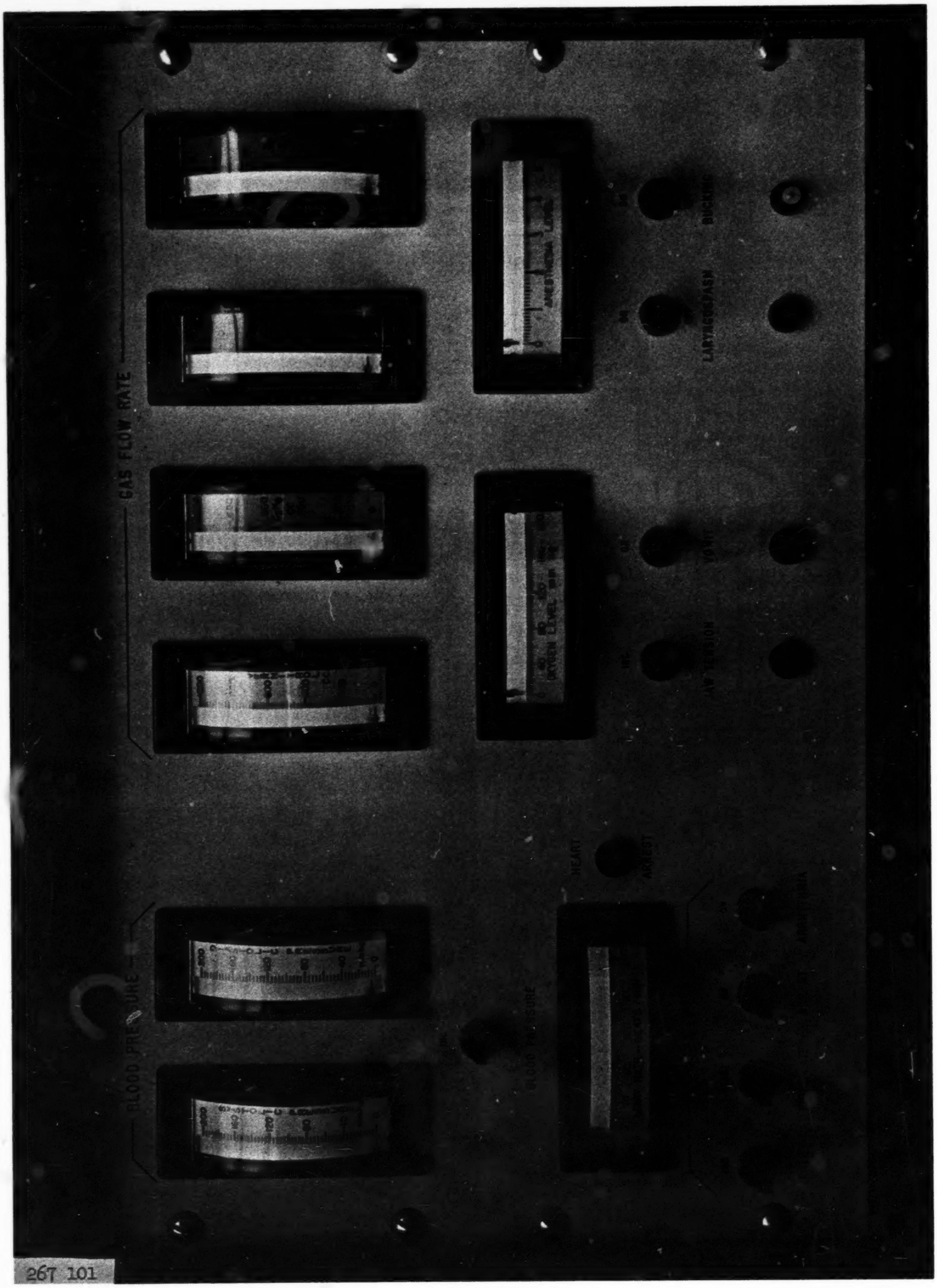
System in Simulated Operating Room

Figure 2


SPHYGMOMANOMETER
ANESTHESIA MACHINE
MANIKIN
RECORDER
INSTRUMENT DRIVE
CUFF PRESSURE
GAS COMPOSITION
GAS FLOW
LUNG-VOLUME
CONTROL
RESPIRATION
COMPUTER
TYPE & QUANTITY
DRUG CONCENTRATION
MOTION SIGNALS
MOTION ACTUATORS
DRUG LEVELS
HEART SOUNDS
LEVEL OF ANESTHESIA
OXYGENATION
BLOOD PRESSURE
PULSE SOUND
PULSE DRIVE
HEART SOUND
CIRCULATION
HEART SOUND
OVERRIDES
MASK & AIRWAY STATUS
TROUBLE INPUT
MONITORING
AIRWAY
STETHOSCOPE
MASK & AIRWAY STATUS
INSTRUCTOR'S CONSOLE

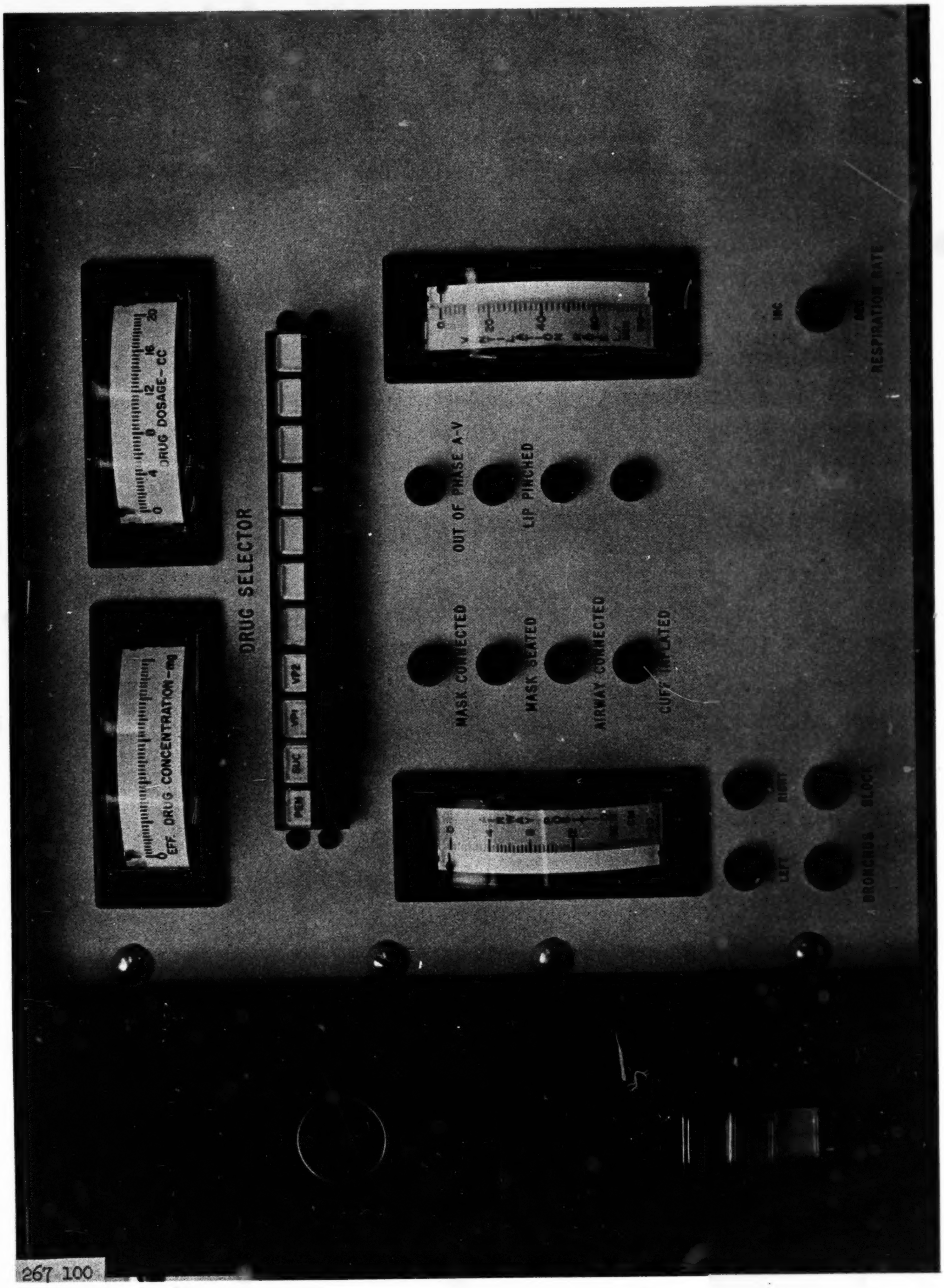
System Block Diagram

Figure 3


GAS FLOW RATE
ANESTHESIA LEVEL
OXYGEN LEVEL
LARYNGOSPASM
BUCKING
HYPOTENSION
HEART
ARREST
BLOOD PRESSURE
267 101

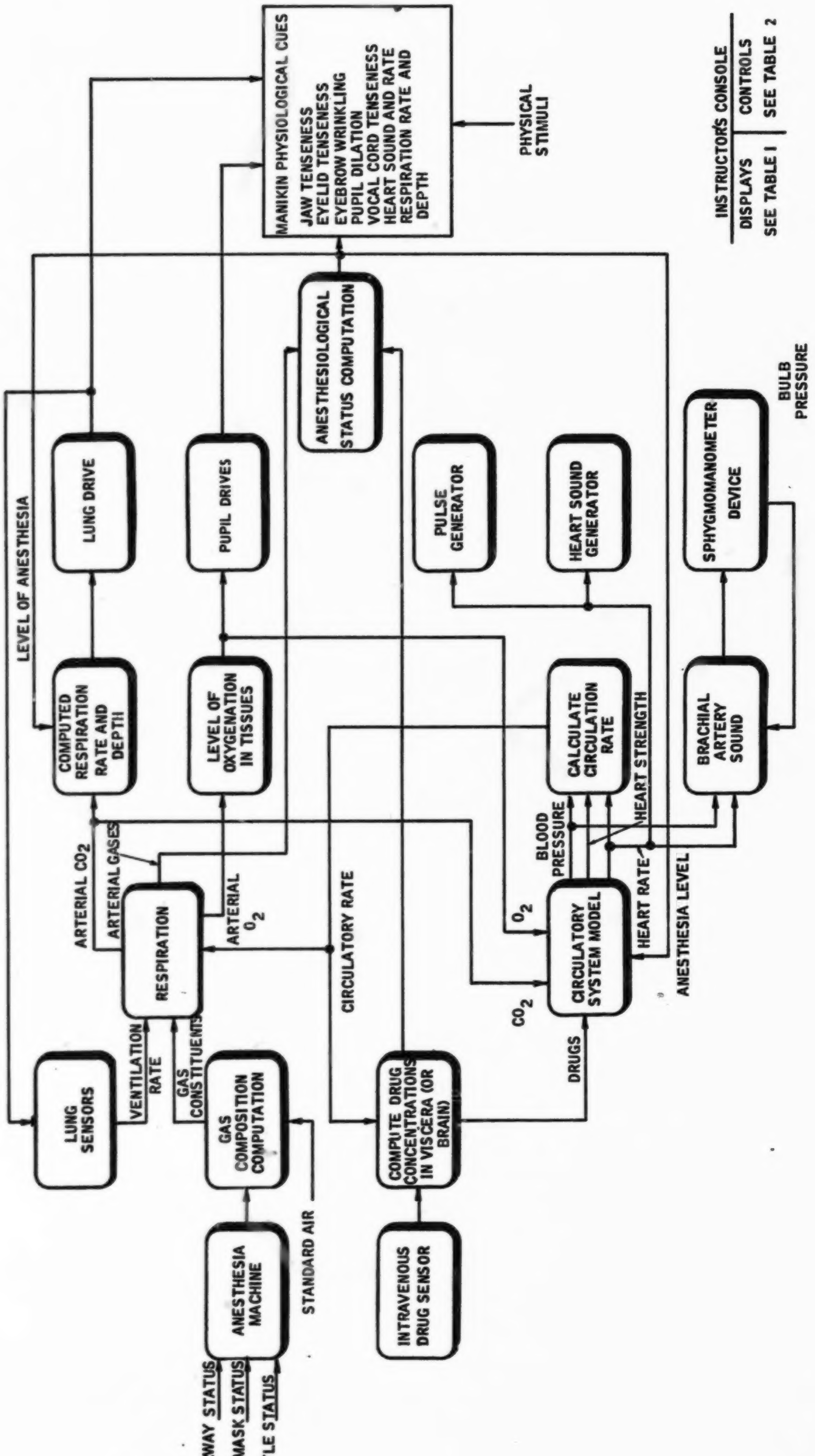
Instructor's Console, Left-Hand Control Panel

Figure 4


DRUG DOSAGE-CC
EFF. DRUG CONCENTRATION-mg
DRUG SELECTOR
PEN
SUC
VP1
VP2
OUT OF PHASE A-V
LIP PINCHED
MASK CONNECTED
MASK SEATED
AIRWAY CONNECTED
CUFF INFLATED
INC
DEC
RESPIRATION RATE
LEFT
RIGHT
BRONCHUS BLOCK
267 100

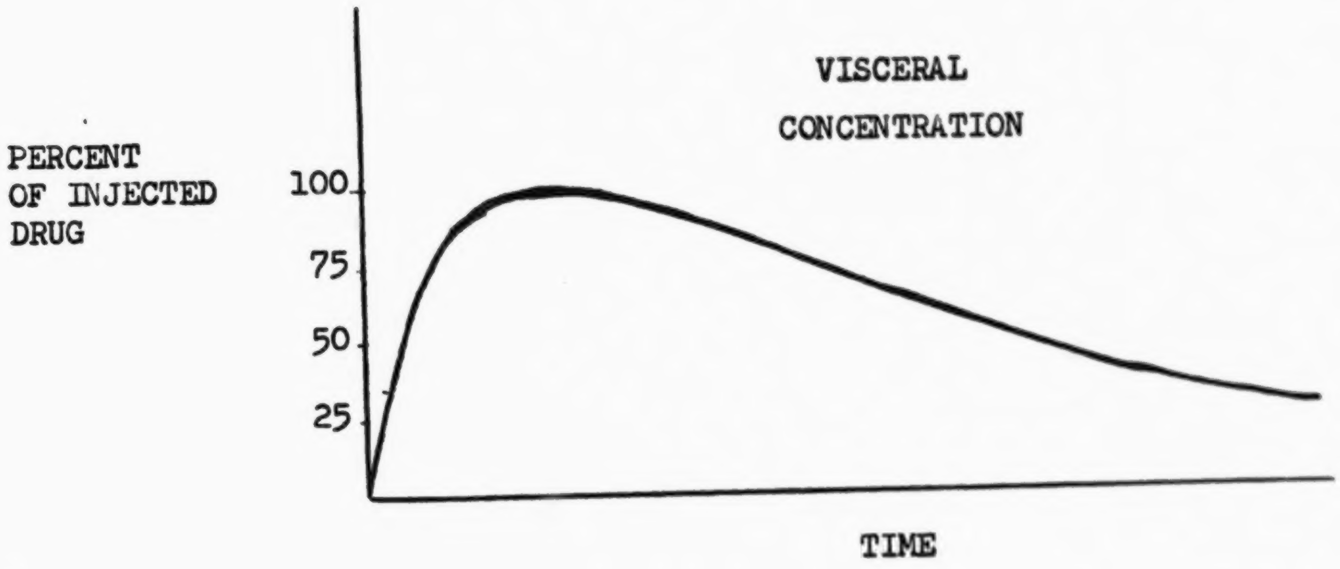
Instructor's Console, Right-Hand Control Panel

Figure 5

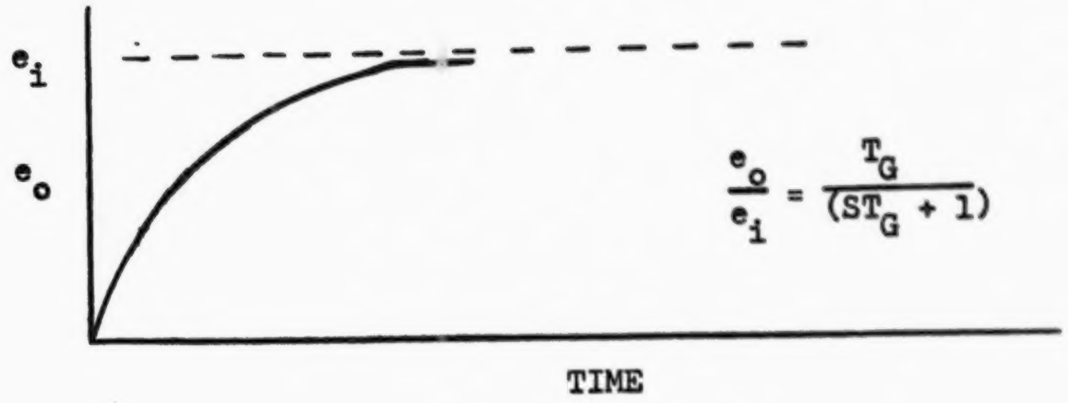

AIRWAY STATUS
FACE-MASK STATUS
BOTTLE STATUS
ANESTHESIA MACHINE
STANDARD AIR
INTRAVENOUS DRUG SENSOR
LUNG SENSORS
GAS COMPOSITION COMPUTATION
COMPUTE DRUG CONCENTRATIONS IN VISCERA (OR BRAIN)
VENTILATION RATE
GAS CONSTITUENTS
DRUGS
RESPIRATION
CIRCULATORY RATE
CO2
O2
CIRCULATORY SYSTEM MODEL
ANESTHESIA LEVEL
HEART RATE
BLOOD PRESSURE
HEART STRENGTH
ARTERIAL CO2
ARTERIAL GASES
ARTERIAL O2
LEVEL OF ANESTHESIA
COMPUTED RESPIRATION RATE AND DEPTH
LEVEL OF OXYGENATION IN TISSUES
CALCULATE CIRCULATION RATE
BRACHIAL ARTERY SOUND
LUNG DRIVE
PUPIL DRIVES
PULSE GENERATOR
HEART SOUND GENERATOR
SPHYGMOMANOMETER DEVICE
BULB PRESSURE
ANESTHESIOLOGICAL STATUS COMPUTATION
MANIKIN PHYSIOLOGICAL CUES
JAW TENSENESS
EYELID TENSENESS
EYEBROW WRINKLING
PUPIL DILATION
VOCAL CORD TENSENESS
HEART SOUND AND RATE
RESPIRATION RATE AND DEPTH
PHYSICAL STIMULI
INSTRUCTOR'S CONSOLE
DISPLAYS
SEE TABLE I
CONTROLS
SEE TABLE 2

Block Diagram of System Model

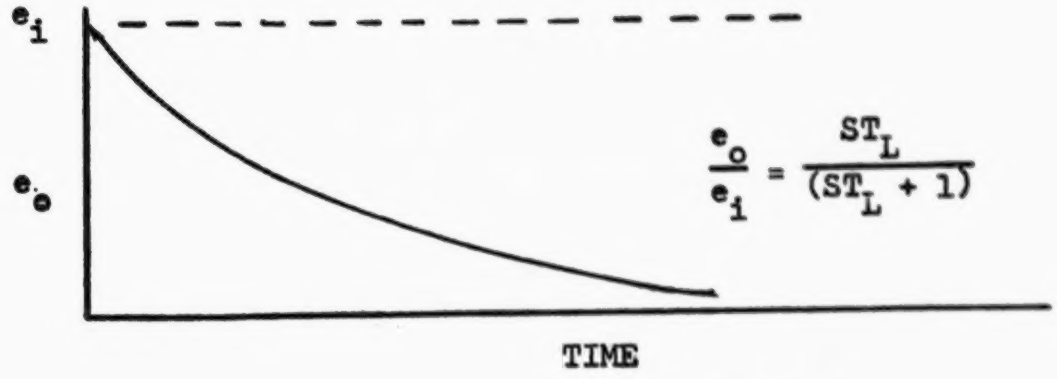
Figure 6



a.



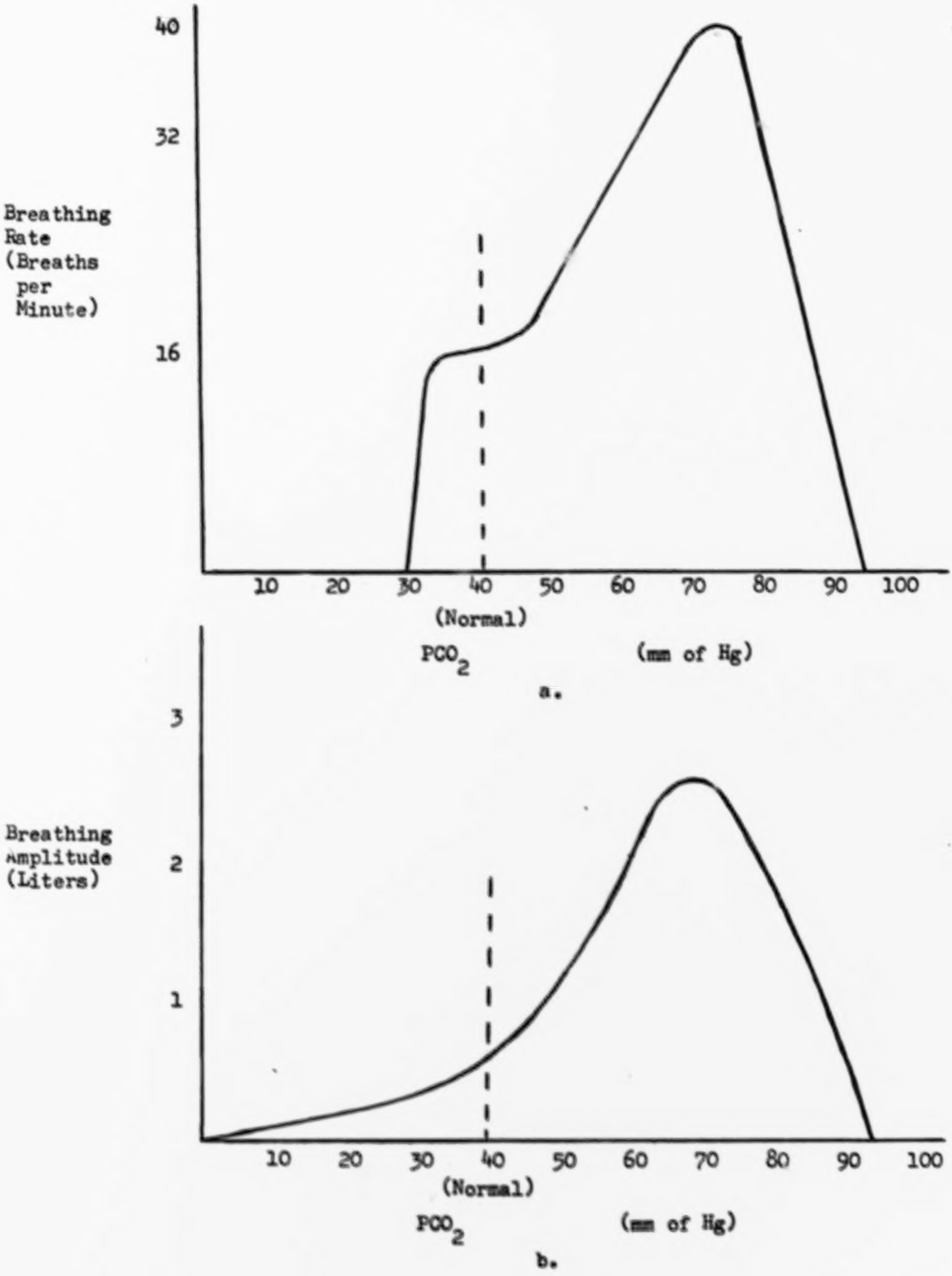
b. LAG



c. LEAD

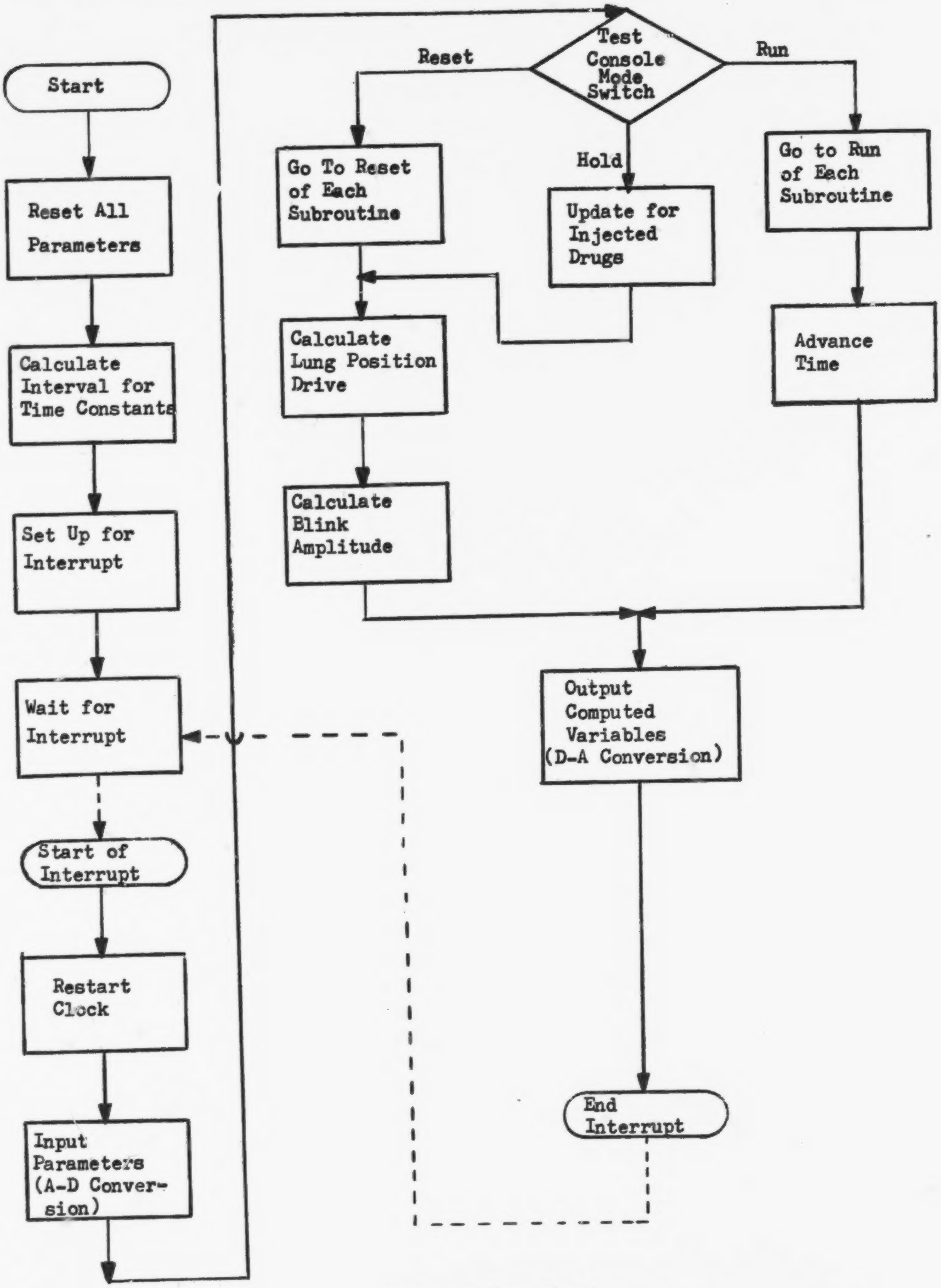
Simulation of Drug Concentration

Figure 7



Effect of CO_2 on Breathing Rate and Amplitude

Figure 8


Start
Reset All Parameters
Calculate Interval for Time Constants
Set Up for Interrupt
Wait for Interrupt
Start of Interrupt
Restart Clock
Input Parameters (A-D Conversion)
Test Console Mode Switch
Reset
Hold
Run
Go To Reset of Each Subroutine
Update for Injected Drugs
Go to Run of Each Subroutine
Calculate Lung Position Drive
Calculate Blink Amplitude
Advance Time
Output Computed Variables (D-A Conversion)
End Interrupt

Program Flow Chart

Figure 9

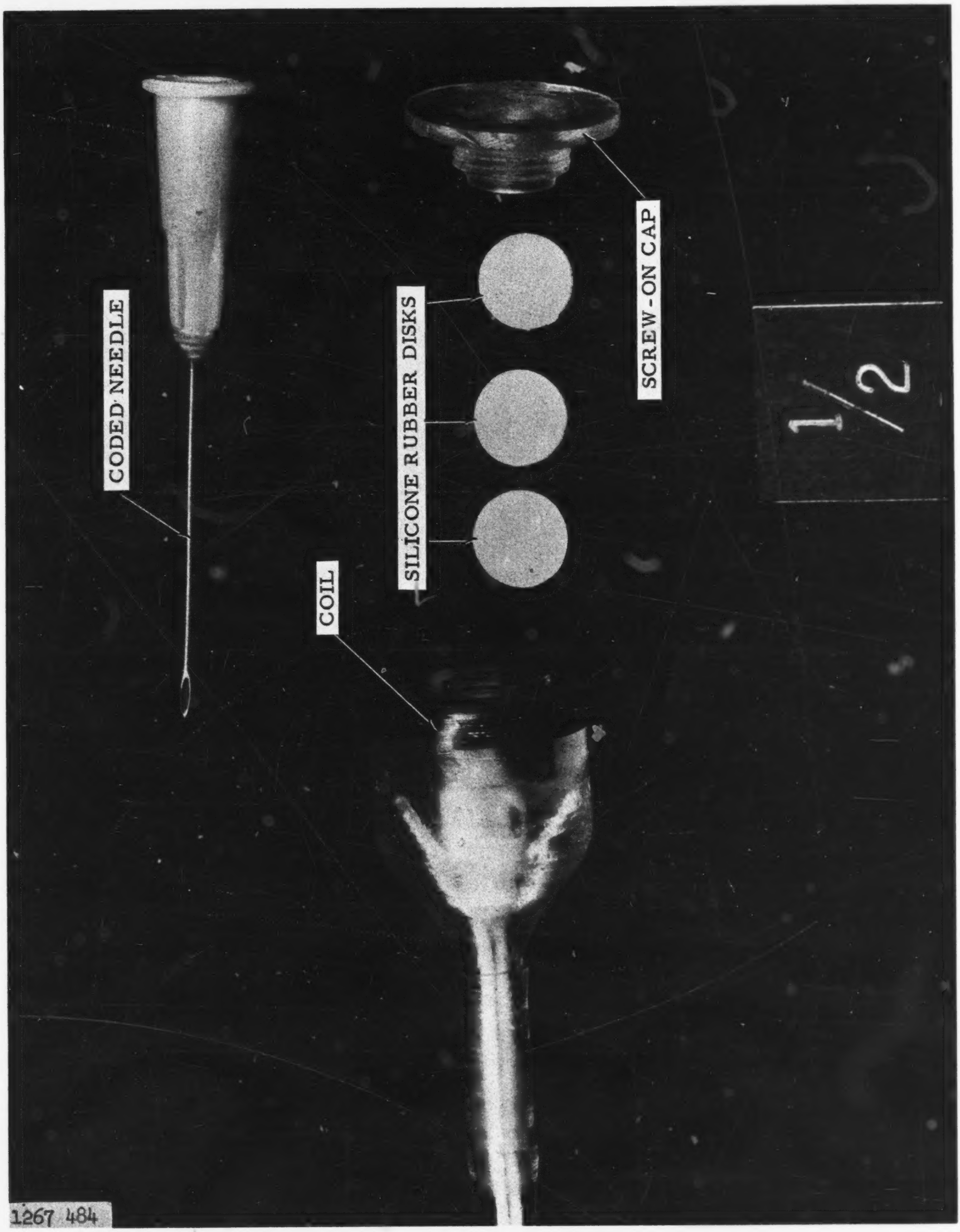
```
          ANESTHESIOLOGICAL TRAINER RECORD

STUDENT:__________________INSTRUCTOR:__________________DATE:_________

TIME        EVENT                          REMARKS
00:10   MASK-ON
00:15   OXYGEN FLOW                        06.00 L.
05:17   PENTOTHAL INJECTED                 50.00 MG.
06:20   PENTOTHAL INJECTED                201.00 MG.
06:25   SUCCINYLCHOLINE INJECTED           40.25 MG.
06:32   MASK-OFF
06:50   FASCICULATION-ON
07:00   FASCICULATION-OFF
07:25   BREATHING STOPPED
08:07   AIRWAY ATTACHED
08:10   OXYGEN FLOW                        04.10 L.
08:15   N2O FLOW                           04.15 L.
10:38   BREATHING STARTED
11:04   BUCKING-ON
11:12   PENTOTHAL INJECTED                103.20 MG.
12:05   BUCKING-OFF
30:20   OXYGEN FLOW                        06.00 L.
30:25   N2O FLOW                           00.00 L.
32:47   AIRWAY REMOVED
END     03
```

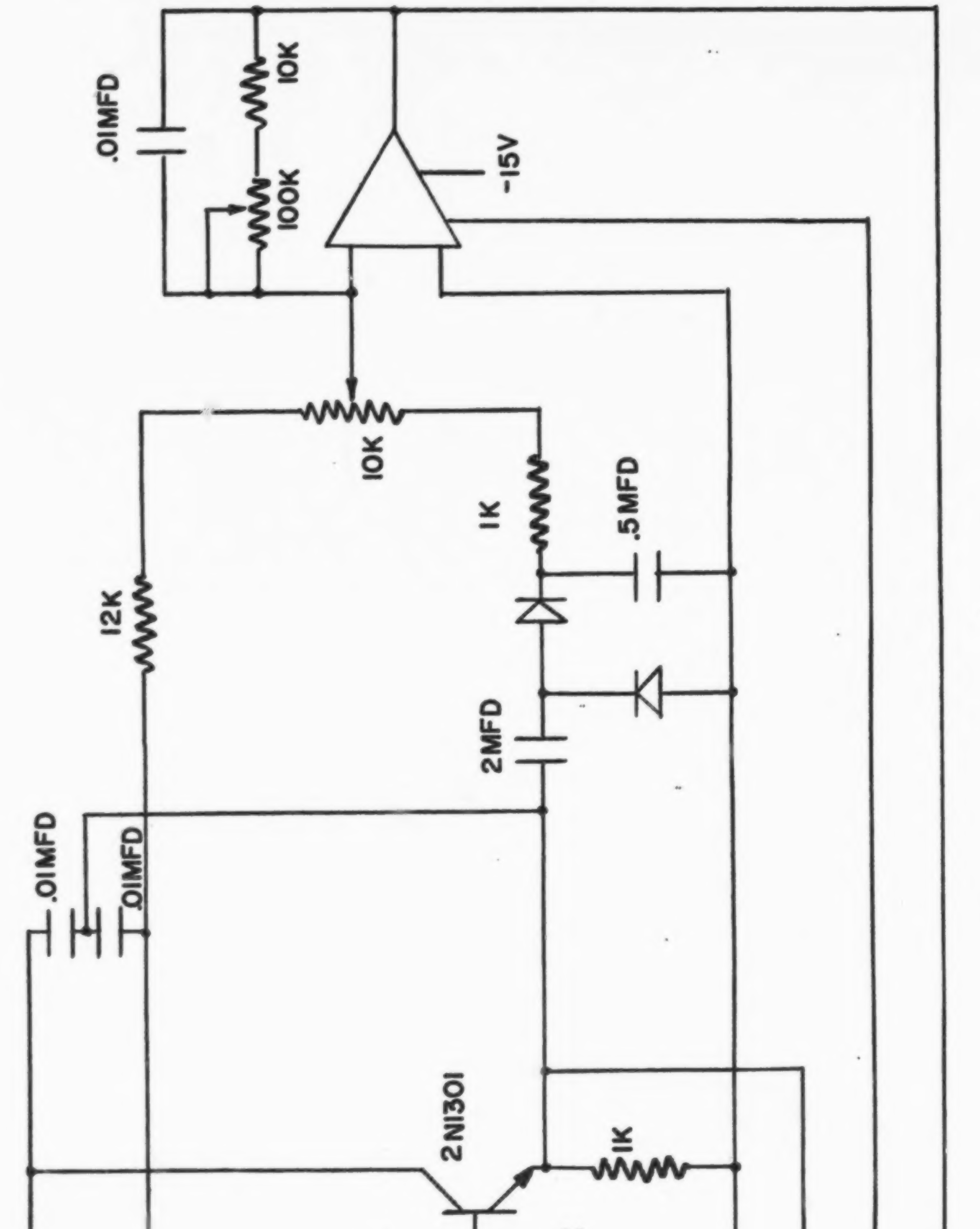
Typical Printout

Figure 10


CODED NEEDLE
SCREW-ON CAP
SILICONE RUBBER DISKS
COIL
1/2
1267 484

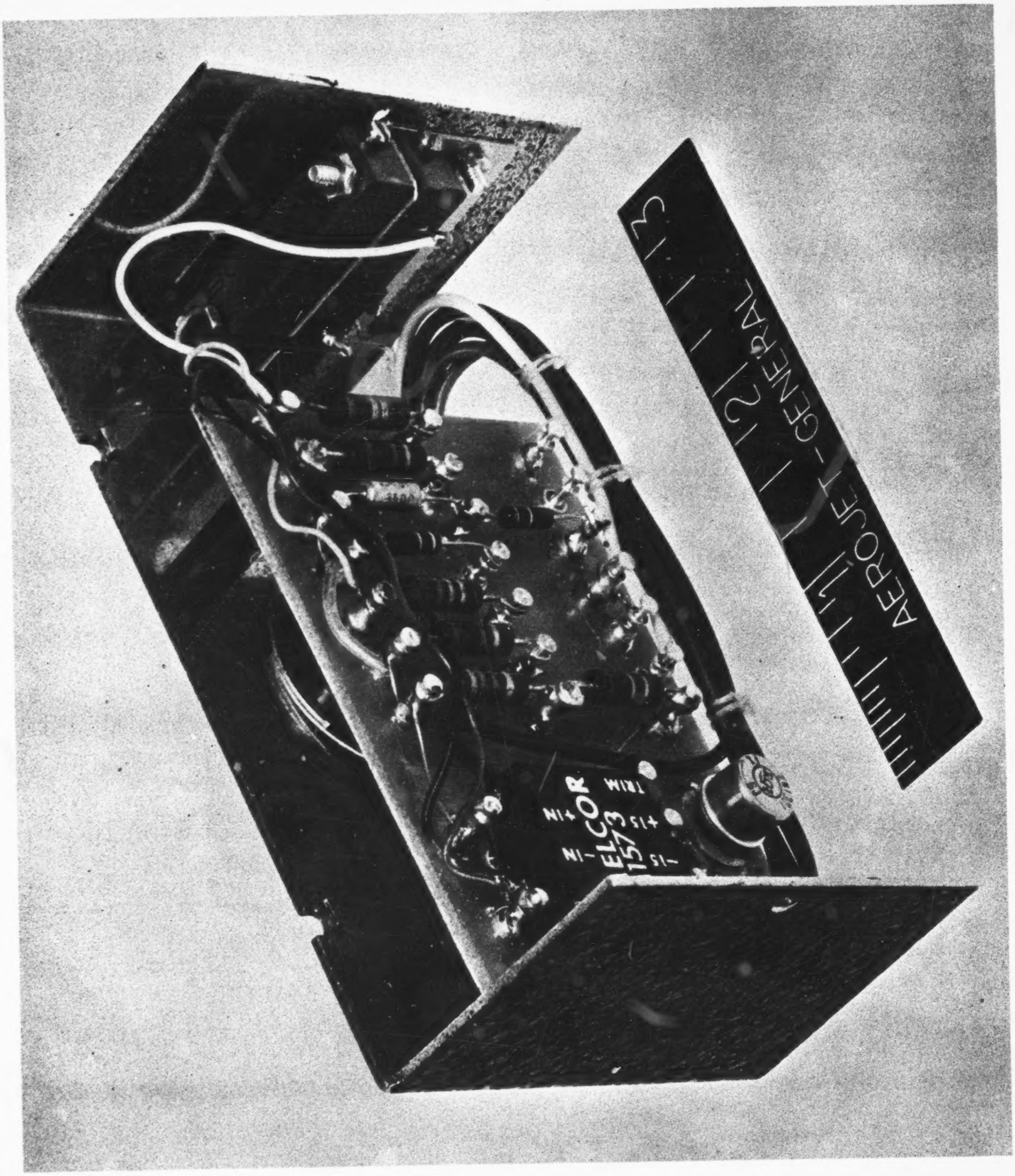
Disassembled Septum Holder

Figure 11


.01MFD
10K
100K
-15V
10K
1K
.5MFD
12K
2MFD
.01MFD
.01MFD
2N1301
1K
12K
8.2K
-15V
GND
OSC. CHECK
+15V
OUTPUT
2
6
5
8
7
3
1
COIL

Needle Sensor, Schematic

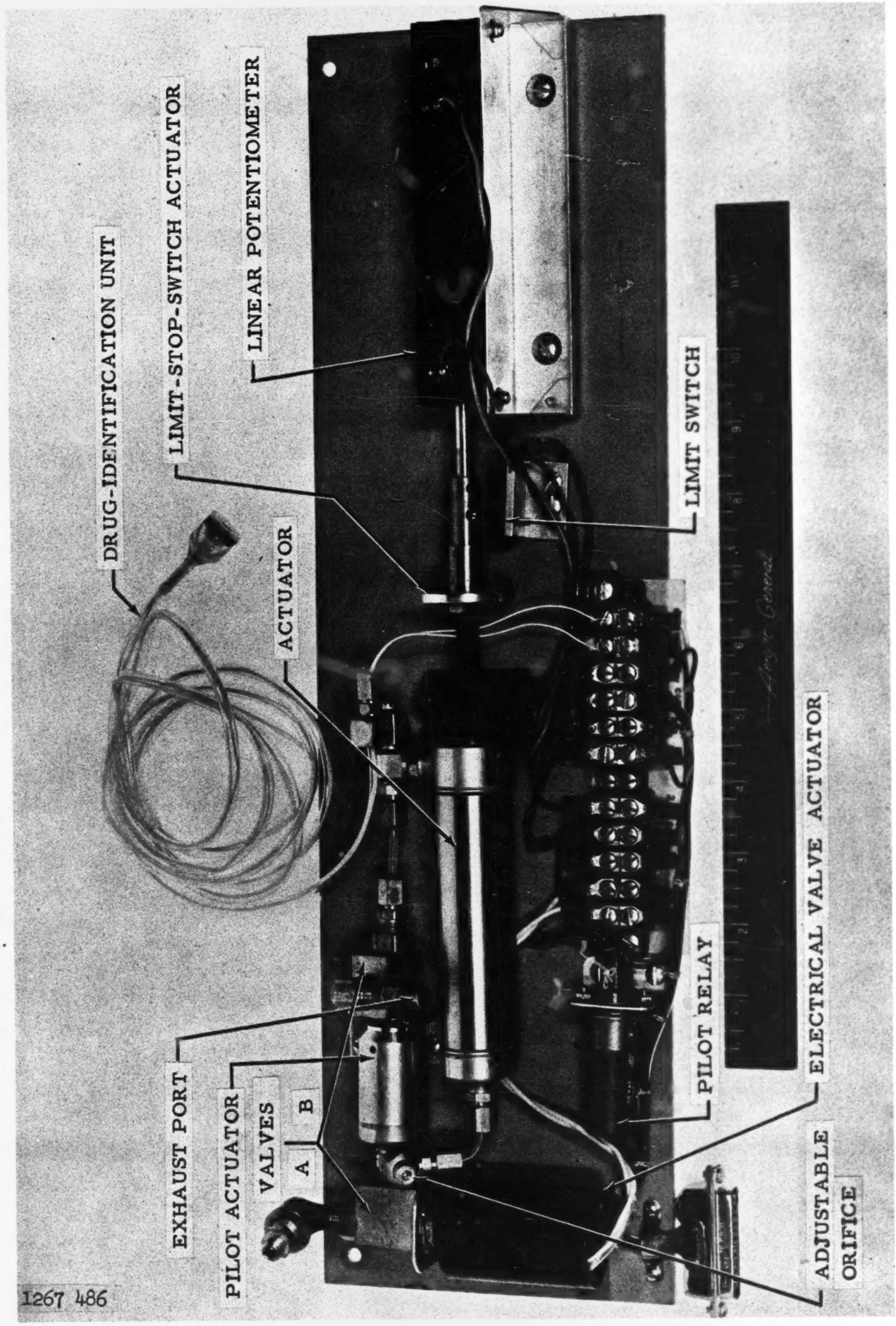
Figure 12


ELCOR
1573
+IN
-IN
+15
-15
TRIM
AEROJET-GENERAL
1
2
3

666 131

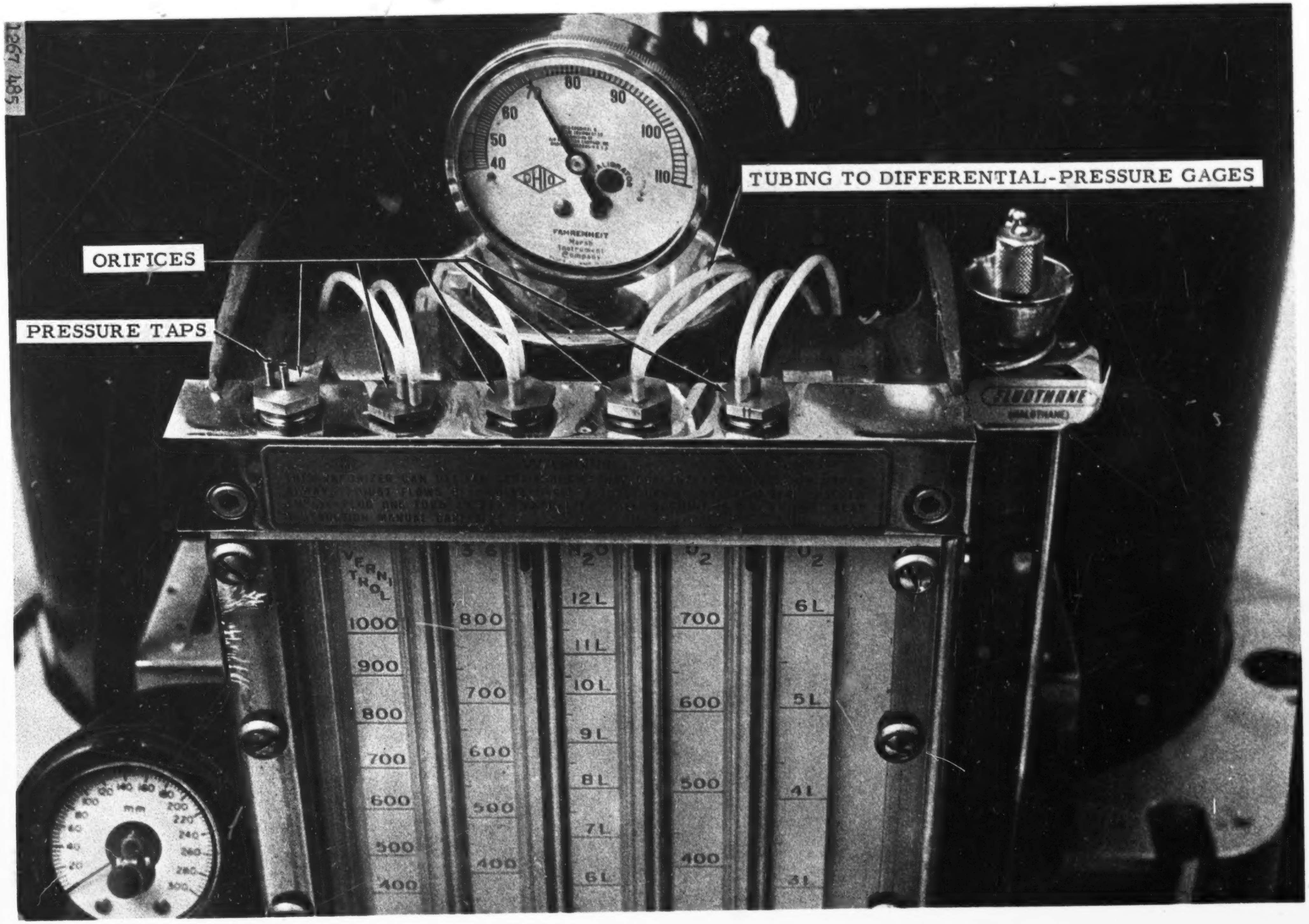
Figure 13

Packaged Drug-Sensing Electronics


DRUG-IDENTIFICATION UNIT
LIMIT-STOP-SWITCH ACTUATOR
LINEAR POTENTIOMETER
ACTUATOR
LIMIT SWITCH
EXHAUST PORT
PILOT ACTUATOR
VALVES
A
B
PILOT RELAY
ELECTRICAL VALVE ACTUATOR
ADJUSTABLE ORIFICE
1267 486

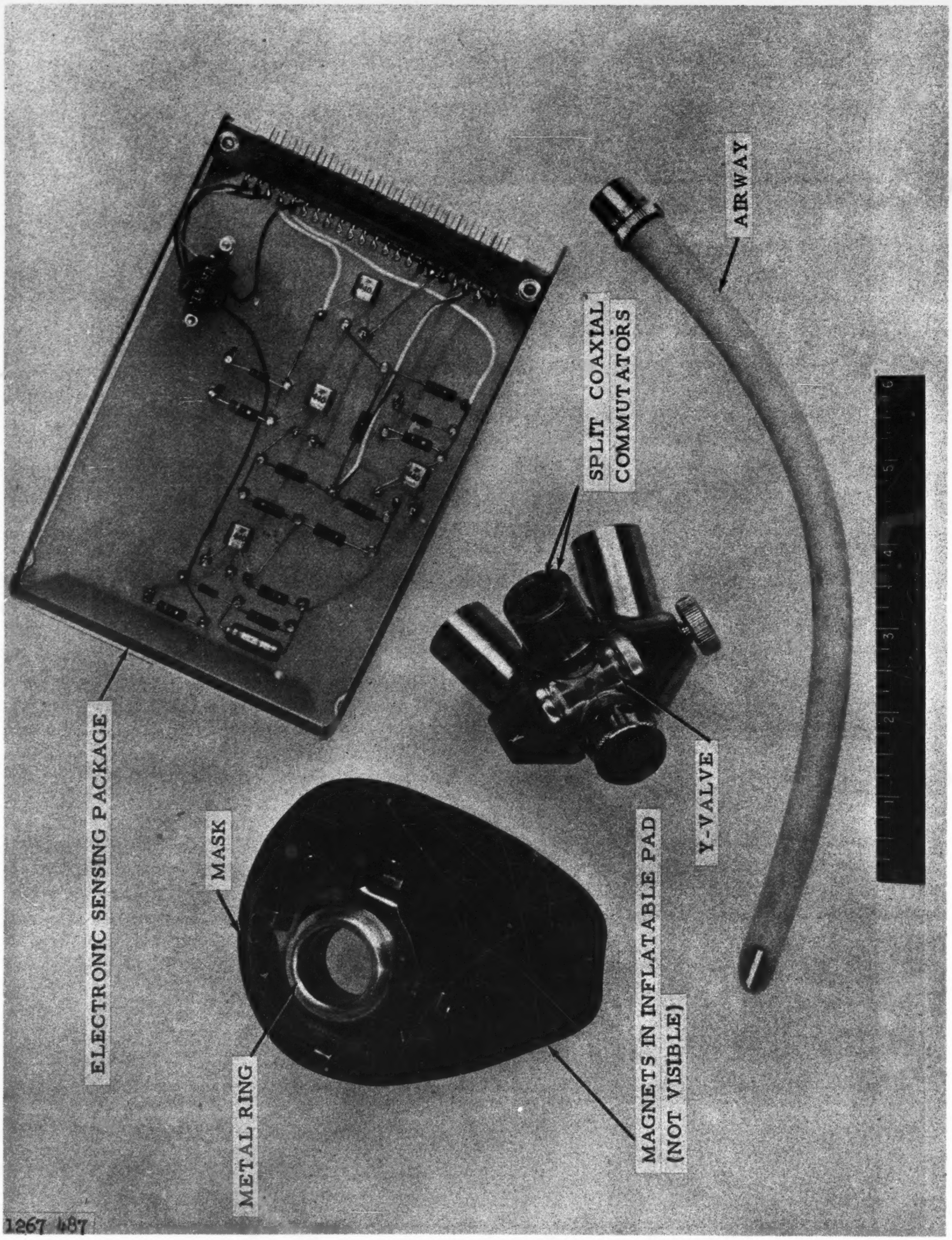
Drug-Metering Mechanism

Figure 14


1267 485
TUBING TO DIFFERENTIAL-PRESSURE GAGES
ORIFICES
PRESSURE TAPS
FLUOTHANE
VERNITROL
N2O
O2
12L
1000
800
700
6L

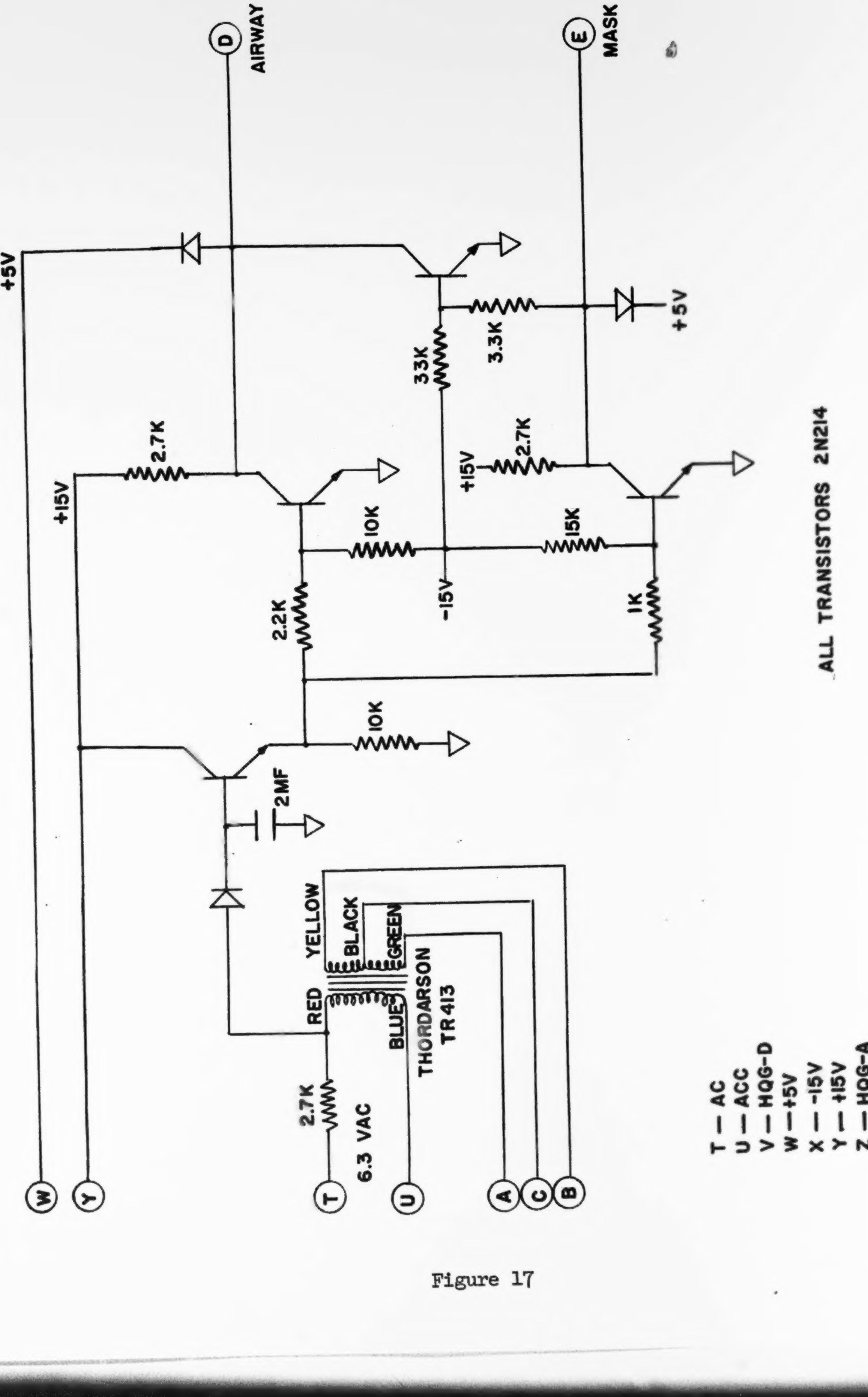
Anesthesia Machine, Flowmeter Modifications

Figure 15


ELECTRONIC SENSING PACKAGE
MASK
METAL RING
MAGNETS IN INFLATABLE PAD
(NOT VISIBLE)
Y-VALVE
SPLIT COAXIAL
COMMUTATORS
AIRWAY
1267 487

Accessories for Modified Anesthesia Machine

Figure 16


D
AIRWAY
E
MASK
+5V
+15V
2.7K
33K
3.3K
+5V
+15V
2.7K
10K
15K
-15V
2.2K
1K
10K
2MF
YELLOW
BLACK
GREEN
RED
BLUE
THORDARSON
TR 413
2.7K
6.3 VAC
W
Y
T
U
A
C
B
ALL TRANSISTORS 2N214
T — AC
U — ACC
V — HQG-D
W — +5V
X — -15V
Y — +15V
Z — HQG-A

Y-Valve Sensor, Schematic

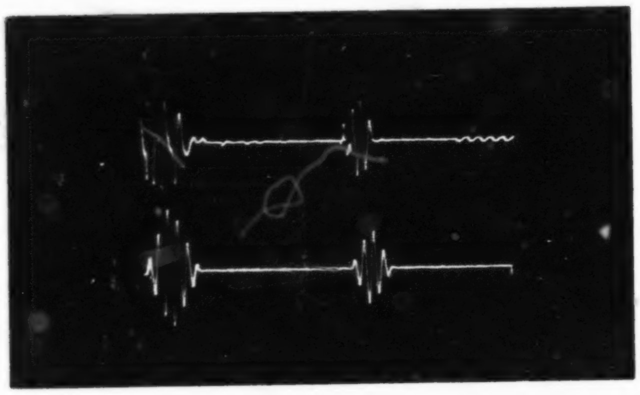
Figure 17

Upper Trace

Heart Sound from
Teaching Tape

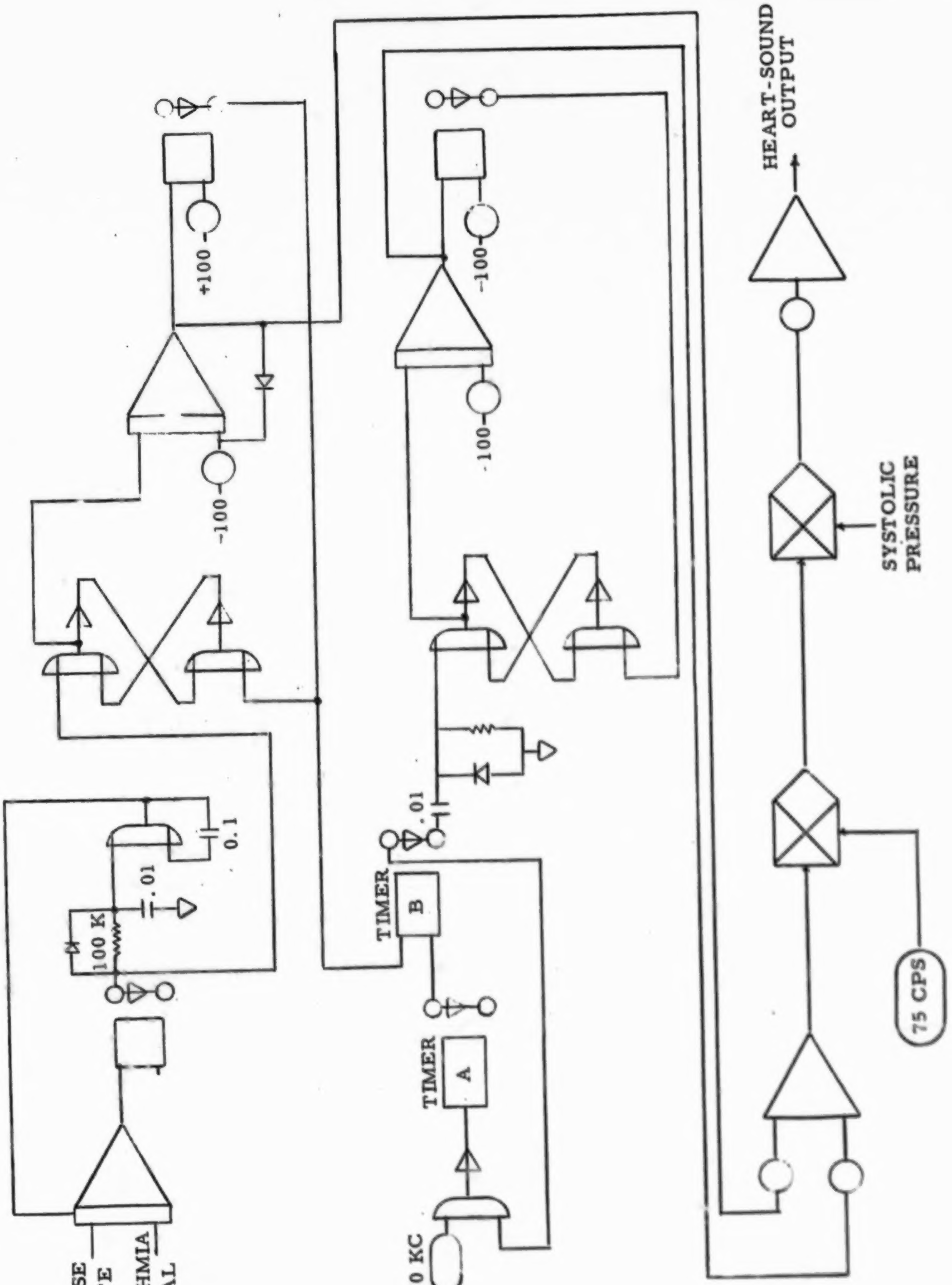
Lower Trace

Heart Sound Generated
by Computer



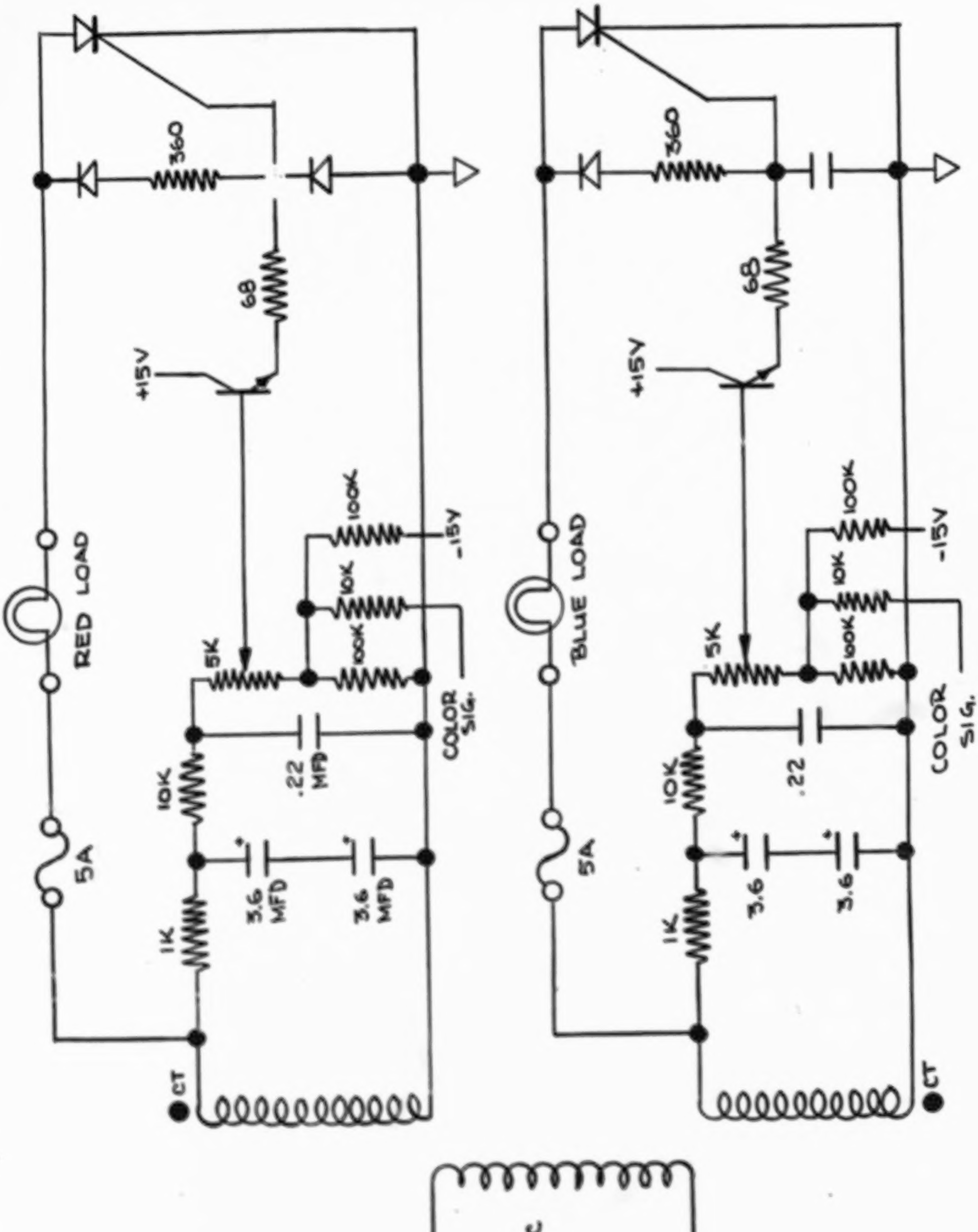
Heart-Sound Comparison, Oscilloscope Traces

Figure 18


PULSE RATE
ARRYTHMIA SIGNAL
100 K
.01
0.1
+100
-100
-100
-100
-100
TIMER B
TIMER A
.01
10 KC
75 CPS
SYSTOLIC PRESSURE
HEART-SOUND OUTPUT

Heart-Sound Generator, Schematic

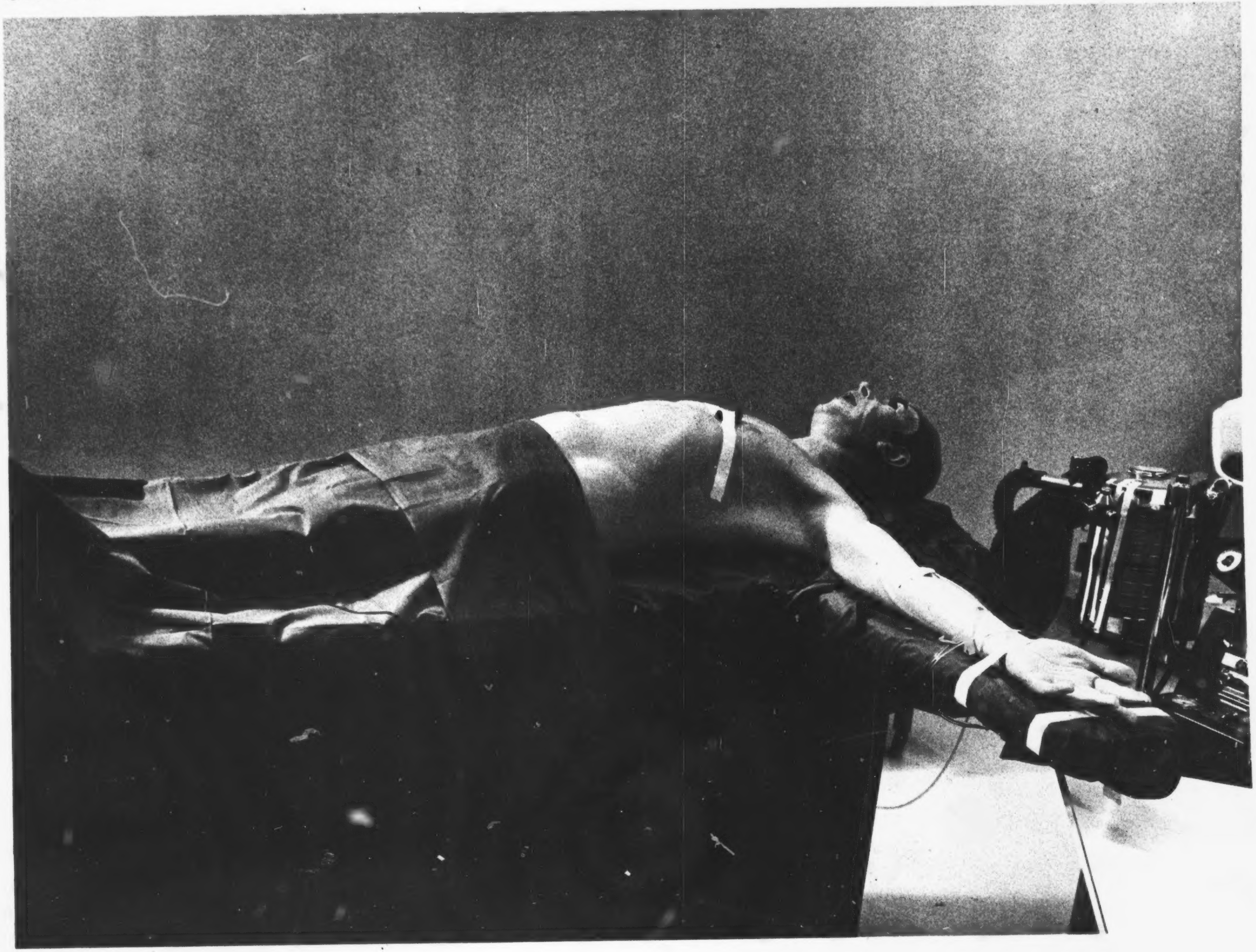
Figure 19


RED LOAD
BLUE LOAD
5A
5A
1K
1K
10K
10K
3.6 MFD
3.6 MFD
3.6
3.6
.22 MFD
.22
5K
5K
100K
10K
100K
100K
10K
100K
-15V
-15V
COLOR SIG.
COLOR SIG.
+15V
+15V
68
68
360
360
CT
CT
115VAC

Color Control, Schematic

Figure 20

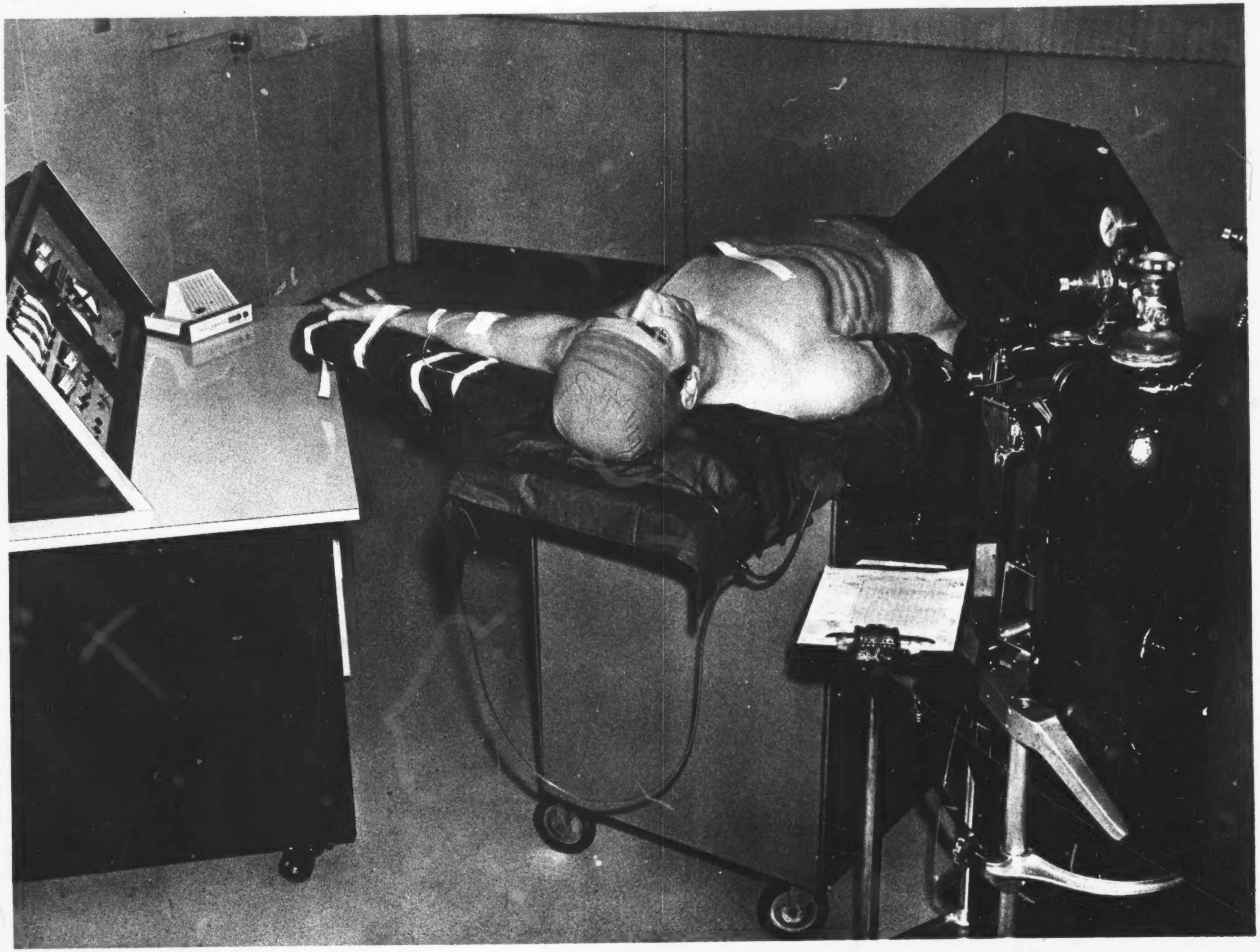
(367-247)



Manikin, as Seen from Instructor's Console

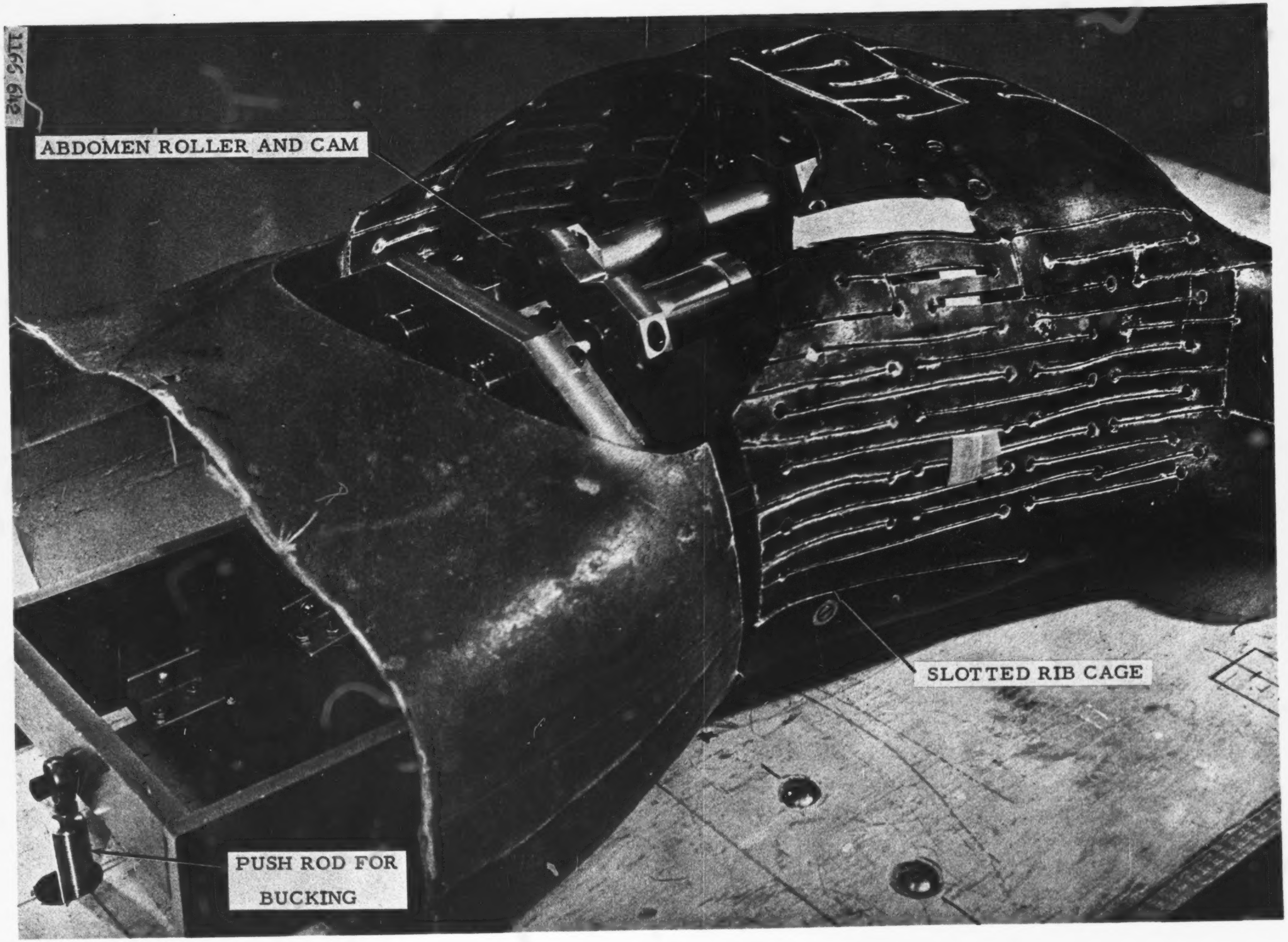
Figure 21

(367-252)



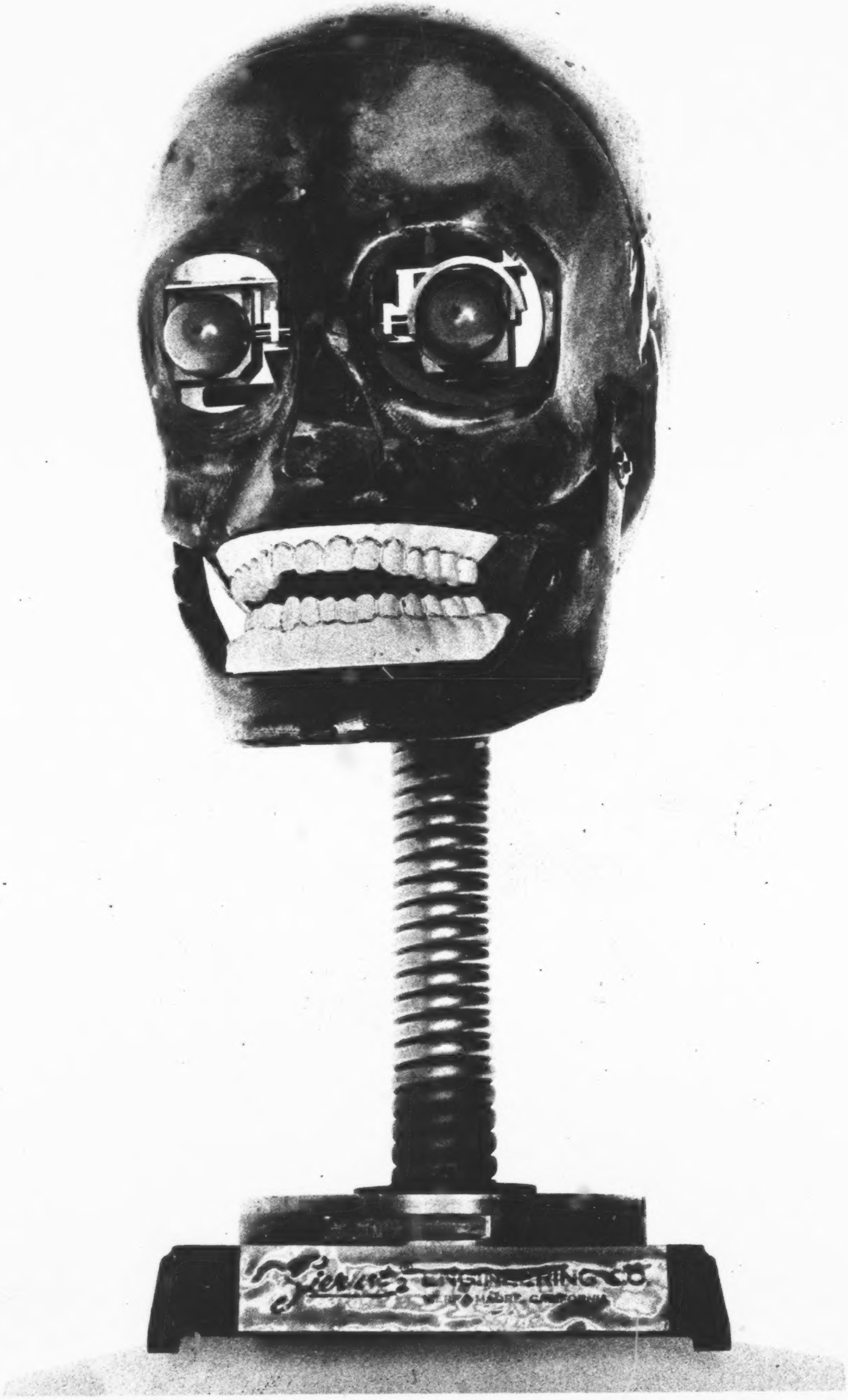
Mankkin, as Viewed by Student

Figure 22


1166 642
ABDOMEN ROLLER AND CAM
SLOTTED RIB CAGE
PUSH ROD FOR BUCKING

Closeup of Manikin's Torso

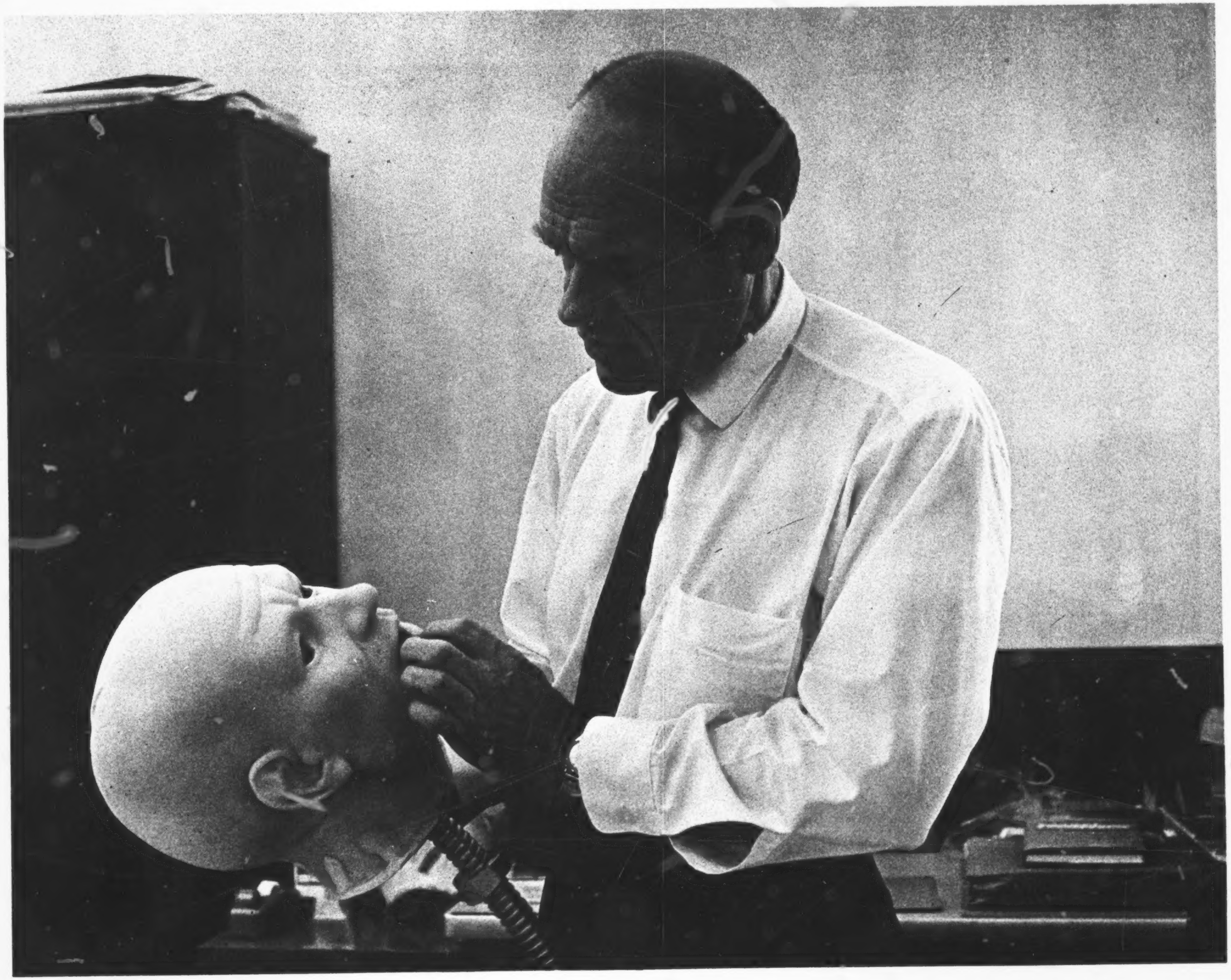
Figure 23


ENGINEERING CO.

Skull, Front View

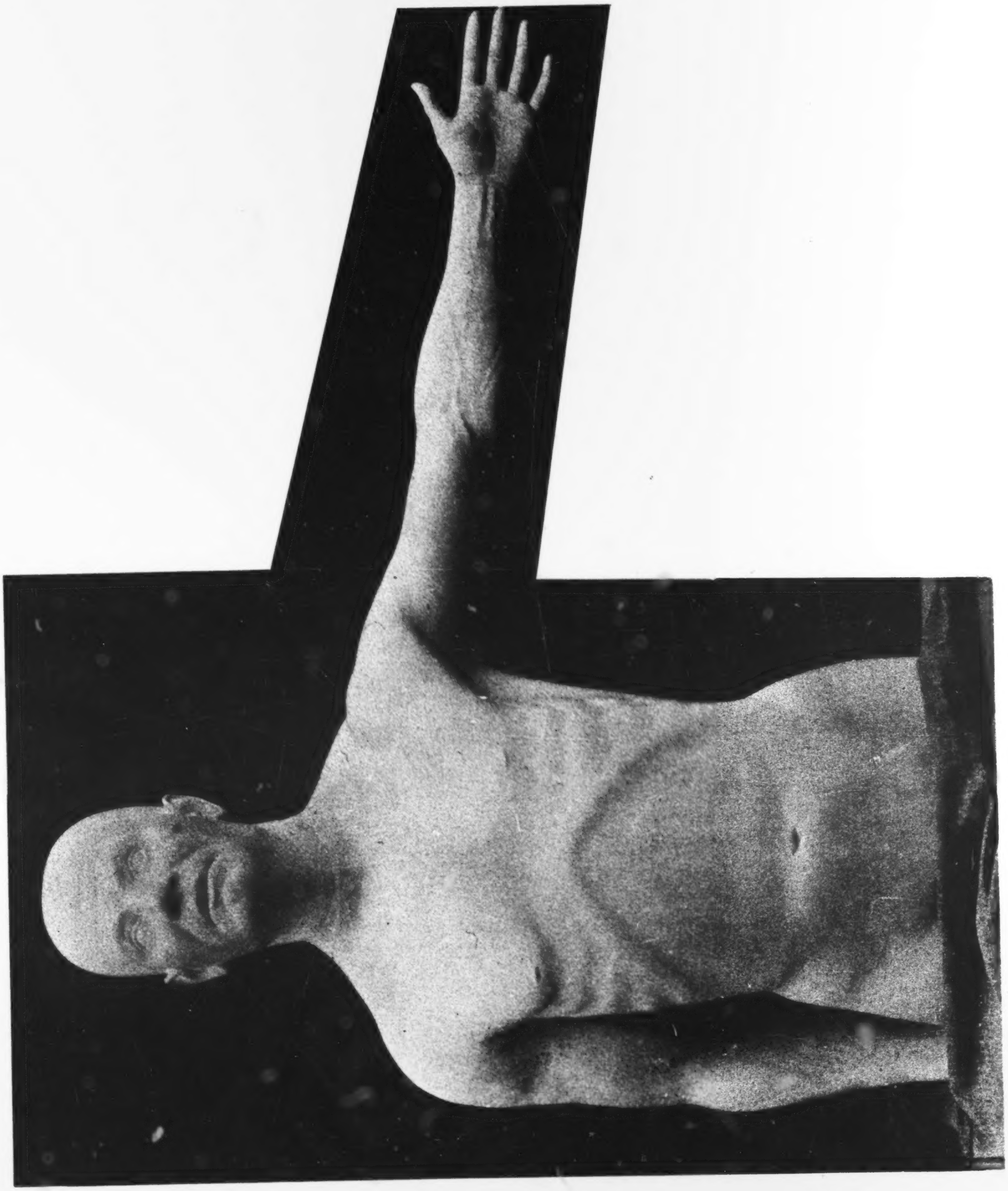
Figure 24

(1166-665)



View Showing Manikin's Skull with Skin in Place

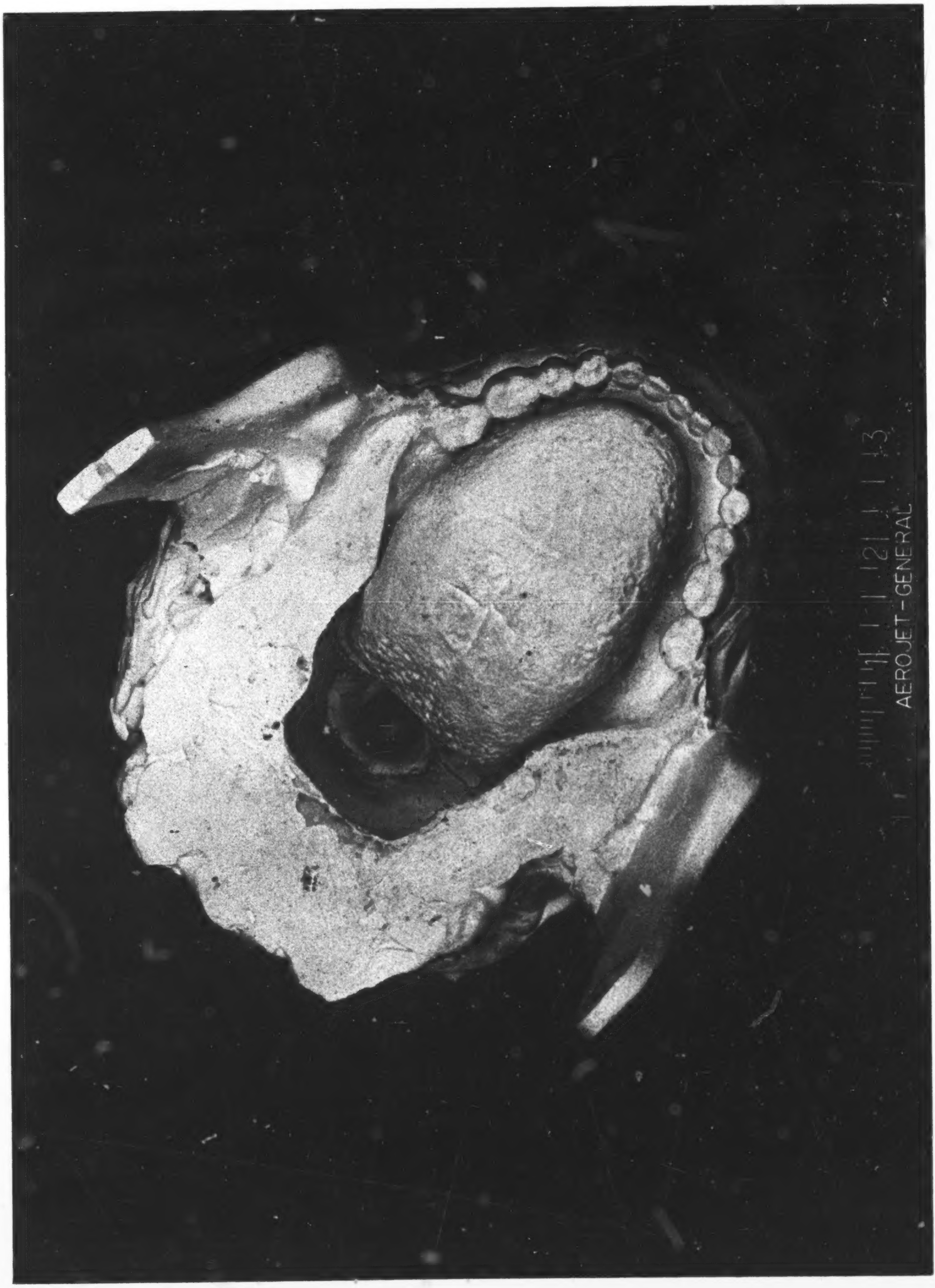
Figure 25



Sculptured Plaster Model of Manikin

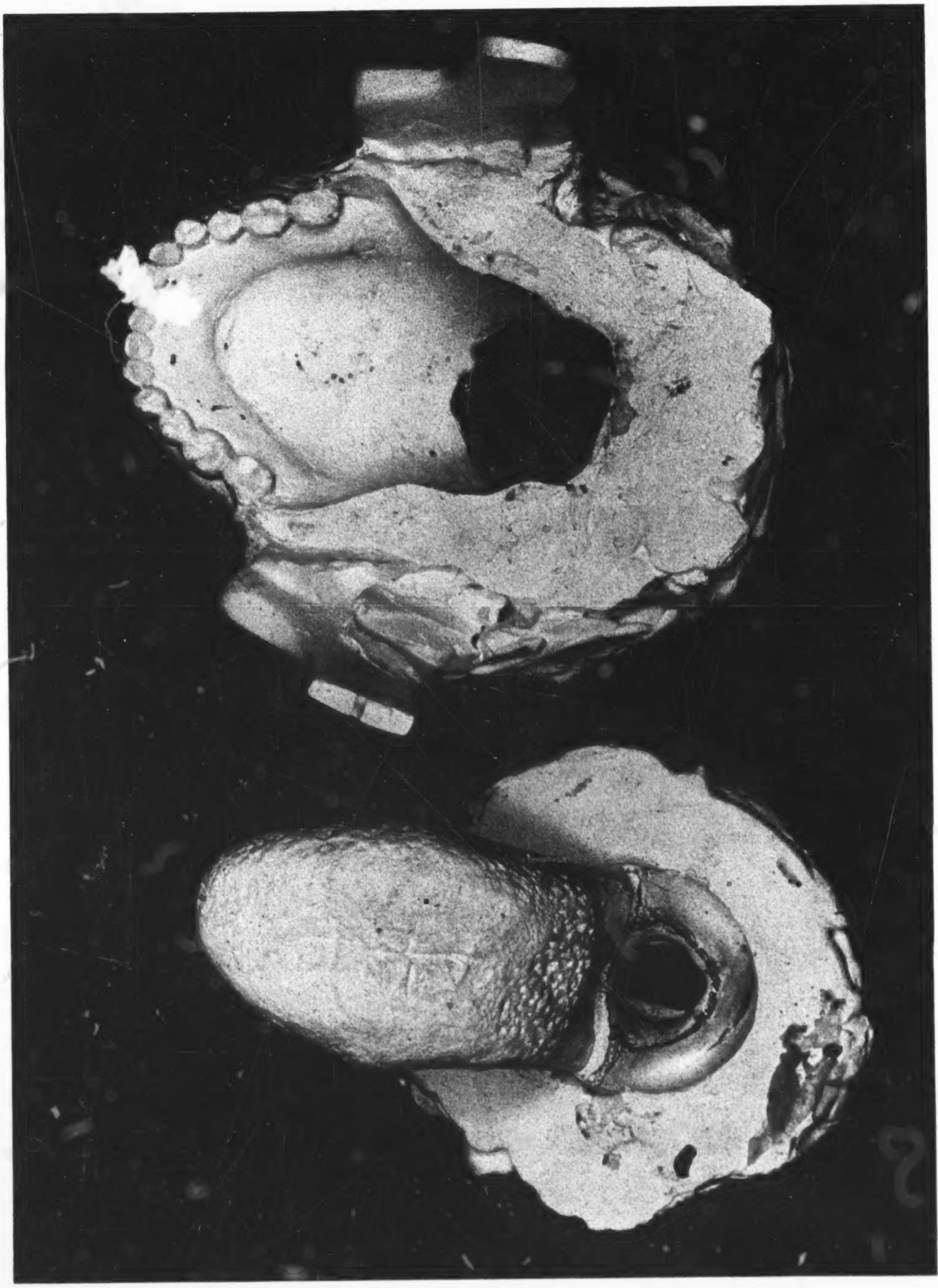
(1066-444)

Figure 26


AEROJET-GENERAL
1
2
3

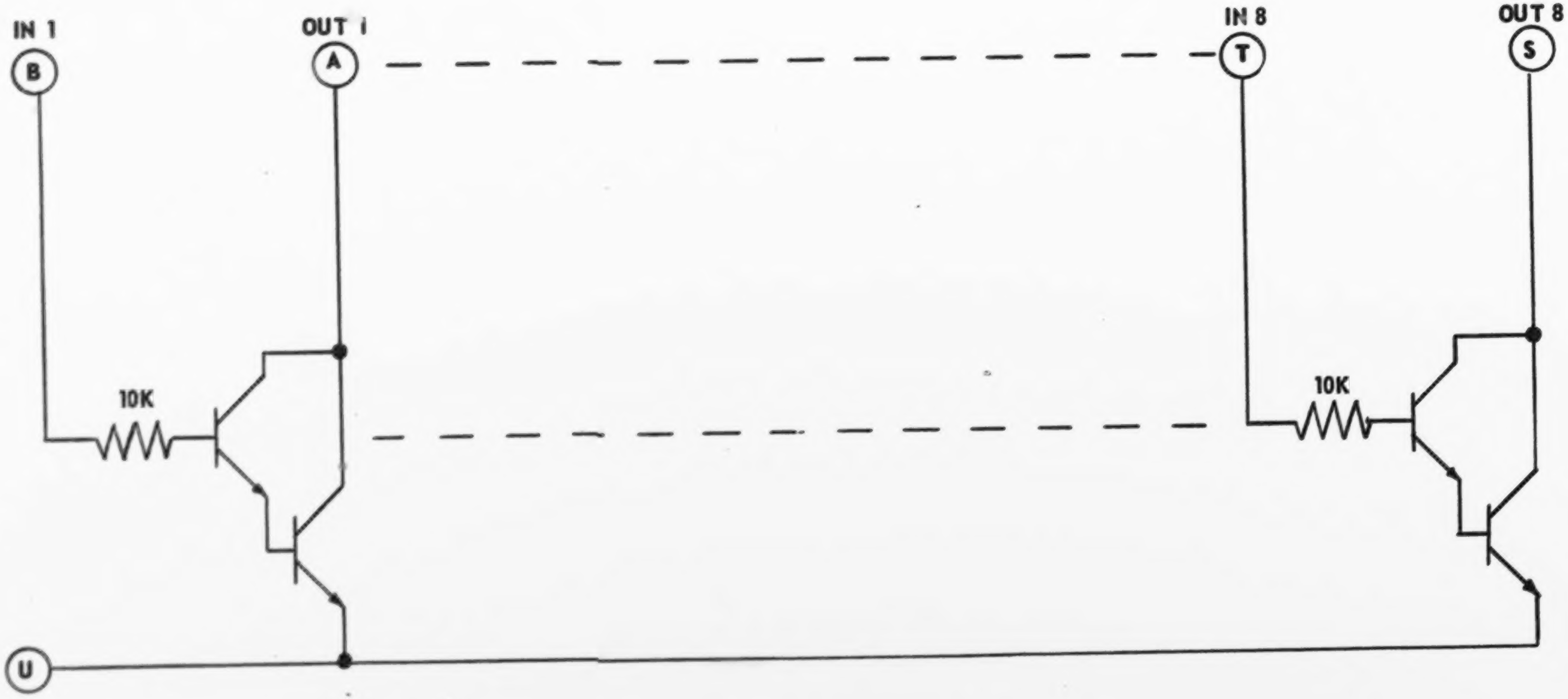
Plaster Model of Tongue, Larynx, and Lower Jaw

Figure 27



Exploded View, Tongue and Lower Jaw

Figure 28

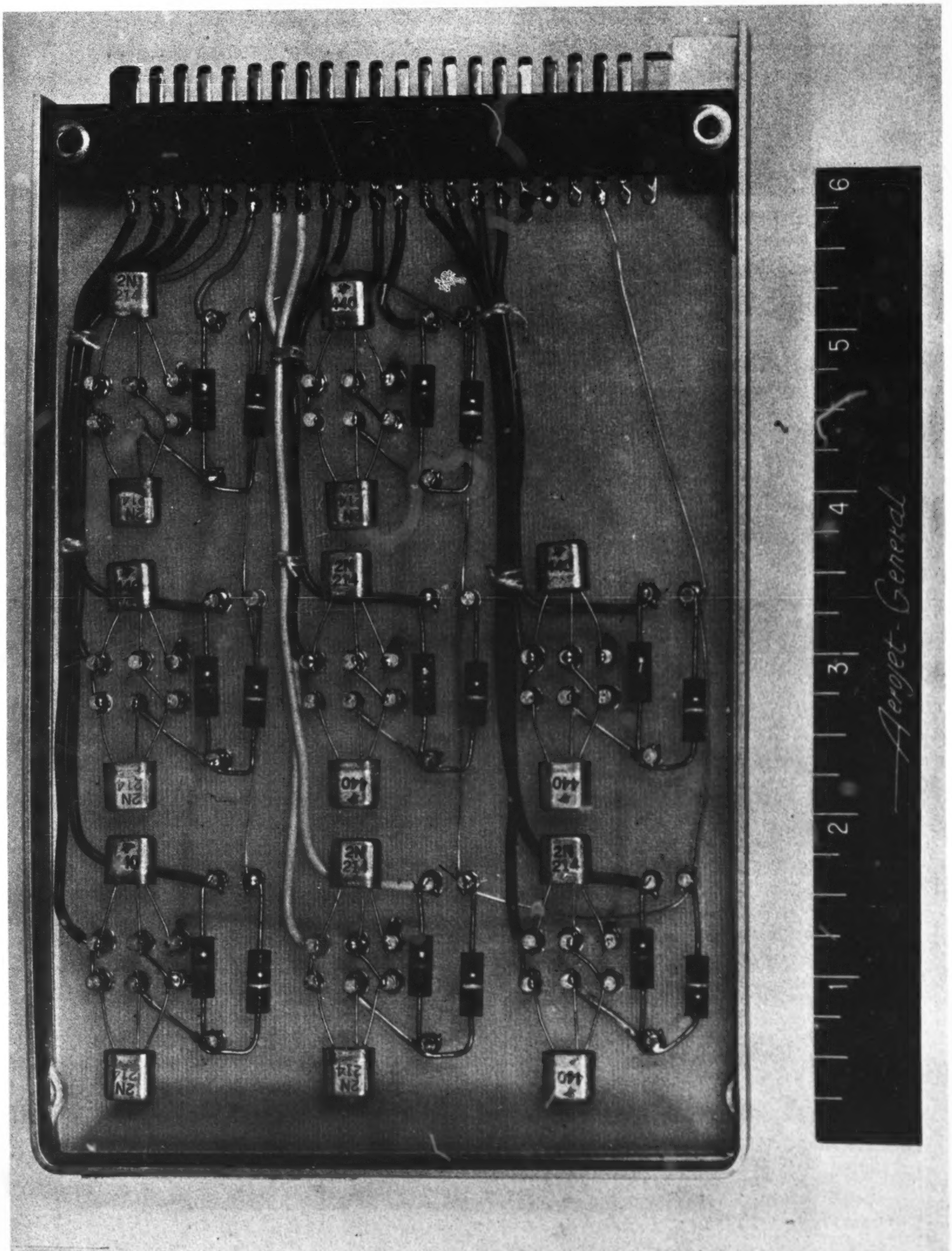

IN 1
B
OUT 1
A
IN 8
T
OUT 8
S
10K
10K
U

A – OUT 1
B – IN 1
C – OUT 2
D – IN 2
E – OUT 3
F – IN 3
H – OUT 4
J – IN 4
K – OUT 5
L – IN 5
M – OUT 6
N – IN 6
P – OUT 7
R – IN 7
S – OUT 8
T – IN 8
U – ACC
V – HQG-D
W – +5 VDC
X – -15 VDC
Y – +15 VDC
Z – HQG-A

ALL TRANSISTORS 2N214

Relay and Lamp Drivers, Schematic

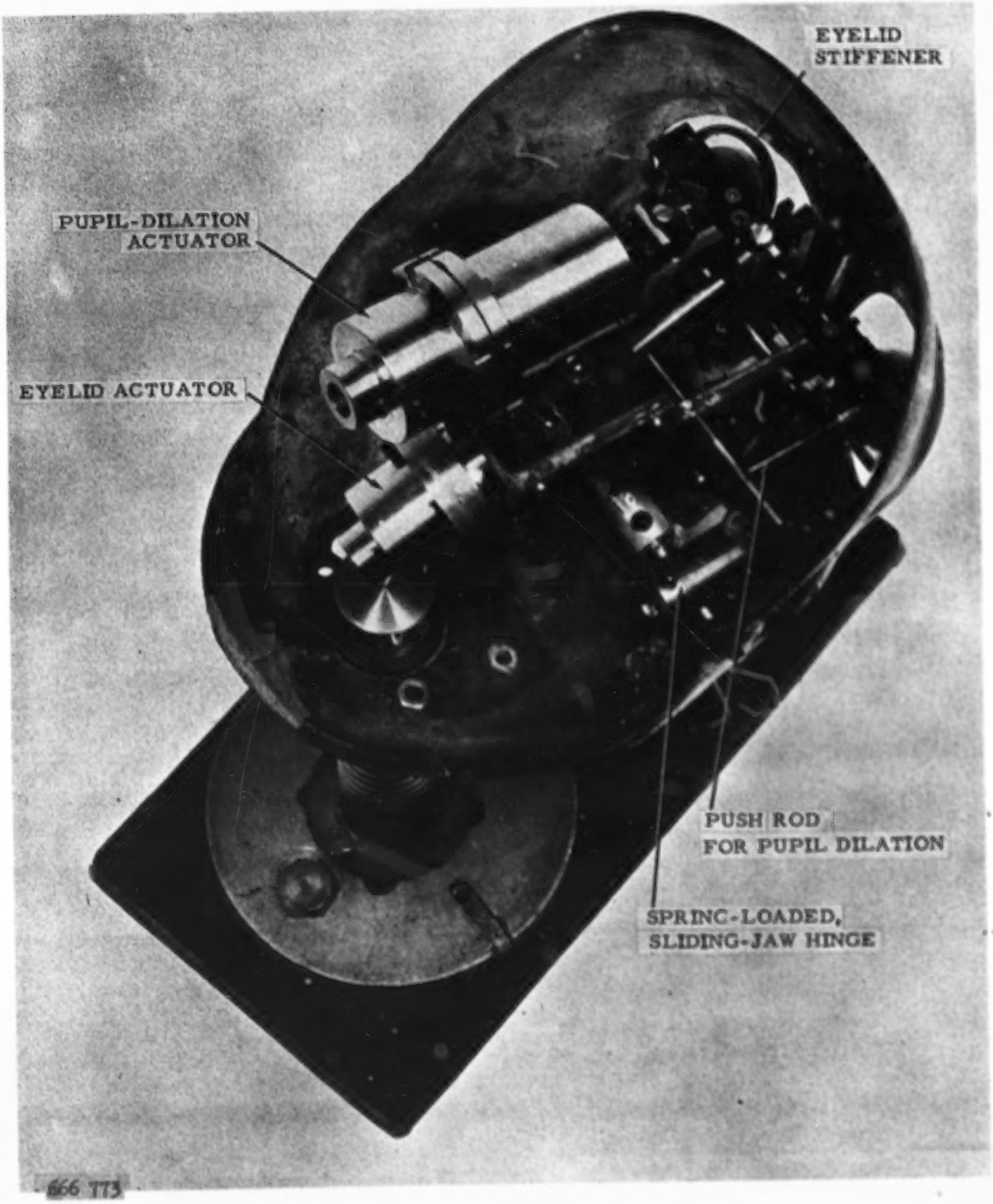
Figure 29


2N 214
440
Aerojet-General
1
2
3
4
5
6

1267 483

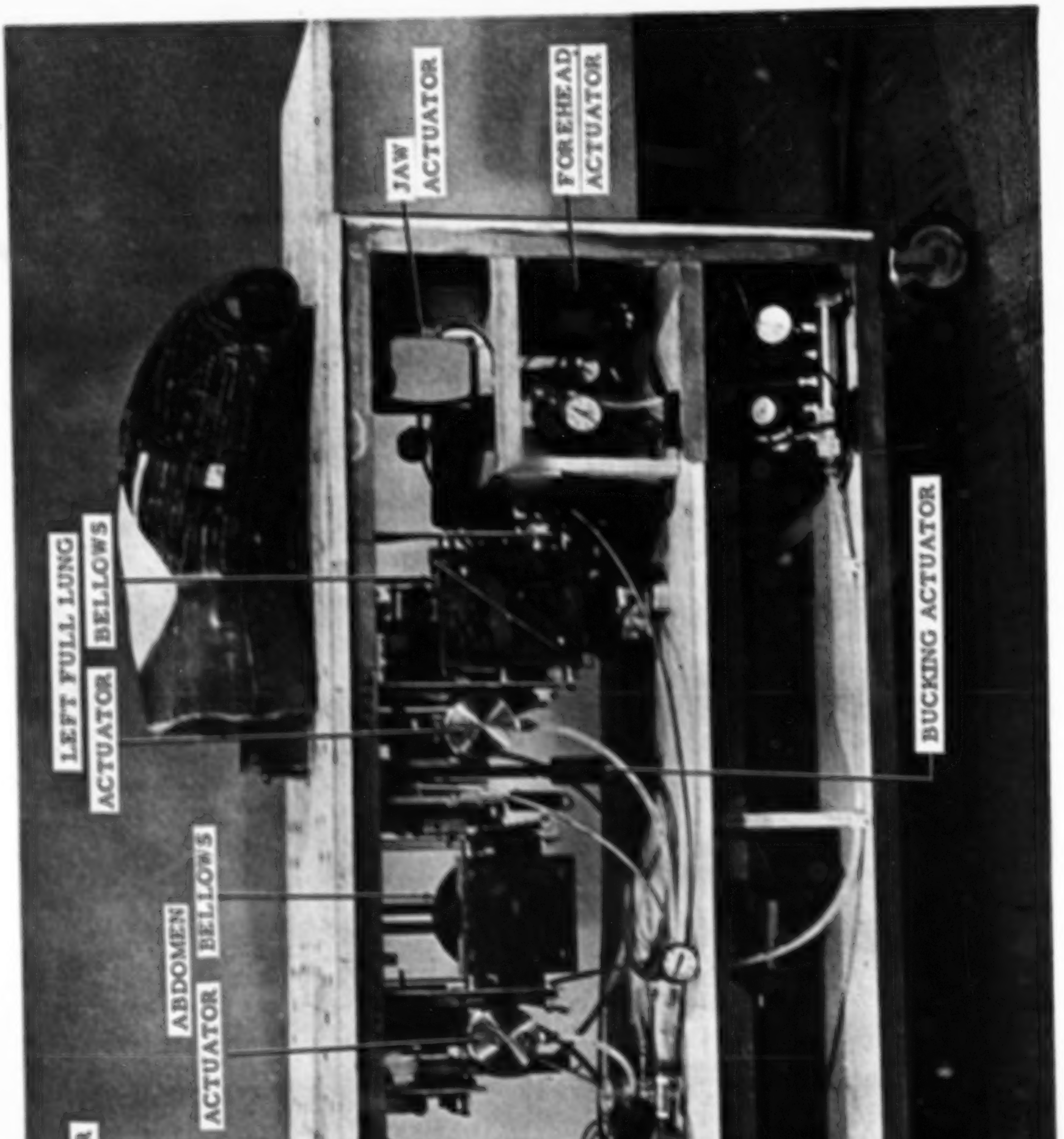
Relay Driver

Figure 30


EYELID
STIFFENER
PUPIL-DILATION
ACTUATOR
EYELID ACTUATOR
PUSH ROD
FOR PUPIL DILATION
SPRING-LOADED,
SLIDING-JAW HINGE
666 773

Skull, Rear View

Figure 31


JAW ACTUATOR
FOREHEAD ACTUATOR
LEFT FULL LUNG ACTUATOR BELLOWS
BUCKING ACTUATOR
ABDOMEN ACTUATOR BELLOWS
LUNG E-P TRANSDUCER
1166 655

Operating Table with Sides Removed, Showing Torso in Position

Figure 32

APPENDIX I

ANESTHESIOLOGICAL EQUATIONS

A. RESPIRATION*

$$B_r = \left[f_1(CO_2) + f_3''(O_2)\right] f_1(O_2)$$

where

B_r = computed breathing rate (breaths/minute)

$f_3''(O_2) \geq 0$

$f_3''(O_2) = 196 \left[f_3(O_2) - 1\right]$ when CO_2 level < 60 mm Hg partial pressure

= 0 when CO_2 level > 60 mm Hg

$$B_a = \left[f_2(CO_2') + f_2(O_2)\right] f_1(O_2)$$

where

B_a = computed breathing amplitude (liters)

$$\text{Ventilation rate} = V_R = B_A B_R \text{ (liters/minute)}$$

where

B_A = amplitude of manikin lung motion

B_R = measured breathing rate

$$\text{Effective ventilation rate} = V_r = V_R \frac{C}{6.5}$$

where

C = circulation (liters/minute)

---

*Functions f_1 through f_3 of O_2, CO_2, and α are shown in Figures I-1 through I-4.

B. CO_2 TRANSFER FUNCTION

$$\frac{CO_{2e}}{CO_{2in}} = \frac{K_{cd}T_{cd}}{sT_{cd} + 1} \quad \left[\text{mm Hg partial pressure/(liter/minute)}\right]$$

where

CO_{2e} = effective CO_2 level in body

CO_{2in} = CO_2 generation rate in body

T_{cd} = $f_1(\alpha)$ = 33/60 min (nominal)

α = $0.08V_r + (0.09/6.5)C + 0.27$

K_{cd} = 3

s = Laplacian operator

C. O_2 TRANSFER FUNCTION

$$\frac{O_{2T}}{O_{2in}} = \frac{K_o}{(T_{s10} + 1)\ (T_{s20} + 1)}$$

where

O_{2in} = O_2(%) in inspired gas x V_r (liters/minute)

O_{2T} = effective oxygen level in tissue (vol%) and 1 vol% = 2.5 volts

T_{20} = 67 sec for $O_{2T} < 52$ volts

T_{10} = $f_2(\alpha)$ = 10 sec (nominal)

K_o = 78.2 liters/min for O_2 input at 0.5 volts

For hyperventilation,

T_{20} = 1340 sec for $O_{2T} > 52$ volts and increasing

T_{20} = 449 sec for $O_{2T} > 52$ volts and decreasing

O_{2T} is limited at 55 volts

D. PENTOTHAL TRANSFER FUNCTION

$$\frac{D_{ep}}{D_p} = \frac{sK_pT_{p3}}{\left(sT_{p2} + 1\right)\left(sT_{p3} + 1\right)} e^{-T_{p1}s}$$

where

D_{ep} = effective concentration (mg) of Pentothal in viscera

D_p = amount of Pentothal injected (mg)

T_{p1} = 20 sec and $e^{-T_{p1}s}$ represents a pure 20-sec delay

T_{p3} = 225 sec

T_{p2} = f(C) = 10 sec (nominal)

K_p = 0.668

E. SUCCINYLCHOLINE TRANSFER FUNCTION

Same equation and T values as for Pentothal, with subscript s substituted for subscript p.

F. VASOPRESSOR TRANSFER FUNCTIONS

1. Methoxamine

$$\frac{D_{ev2}}{D_{v2}} = \frac{K_{v2}}{sT_{v2} + 1} e^{-20s}$$

K_{v2} = 0.668

T_{v2} = f(C) = 15 sec (nominal)

D_{ev2} = effective concentration (mg) of methoxamine

D_{v2} = amount of methoxamine injected (mg)

and e^{-20s} represents a pure 20-sec delay

2. **Ephedrine**

$$\frac{D_{evl}}{D_{vl}} = \frac{K_{vl}}{sT_{vl} + 1} e^{-20s}$$

K_{vl} = 0.668

T_{vl} = f(C) = 60 sec (nominal)

D_{evl} = effective concentration (mg) of ephedrine

D_{vl} = amount of ephedrine injected (mg)

and e^{-20s} represents a pure 20-sec delay. The effect of ephedrine increases linearly with the injected dose until the effective concentration reaches 26 mg. The effect of additional increments is reduced thereafter.

3. **Effective CO_2**

$$CO_2' = CO_2 - K_{pl}D_{ep} - K_{cyl}D_{ecy} \text{ (mm Hg partial pressure)}$$

$$K_{pl} = 2.91 \times 10^{-2}$$

$$K_{cyl} = 1.195 \times 10^{-1}$$

G. CYCLOPROPANE TRANSFER FUNCTION

The following transfer function was not used in the final model, because of the lack of definition with regard to the effects of cyclopropane:

$$\frac{D_{ecy}}{\dot{D}_{cy}} = \frac{K_{cy2}}{\left(sT_{cl} + 1\right)\left(sT_{c2} + 1\right)}$$

where

D_{ecy} = effective concentration of cyclopropane (mm Hg partial pressure)

$\dot{D}_{ey}$ = cyclopropane flow rate (liters/minute)

T_{cl} = 67.5 sec

T_{c2} = $f_3(\alpha)$ = 90 sec (nominal)

K_{cy2} = 100 mm Hg/(liters/minute)

H. N_2O TRANSFER FUNCTION

$$\frac{D_{eno}}{\dot{D}_{no}} = \frac{K_n}{\left(sT_{n1} + 1\right)\left(sT_{n2} + 1\right)}$$

where

D_{eno} = effective concentration of N_2O (mm Hg partial pressure)

$\dot{D}_{no}$ = N_2O flow rate (liters/minute)

T_{n1} = 135 sec

T_{n2} = $f_3(\alpha)$ = 90 sec (nominal)

K_n = 100 mm Hg/(liters/minute)

I. CIRCULATION PARAMETERS

$$C = K_c P_r P_s$$

where

C = 6.5 liters/minute (nominal)

P_r = pulse rate (pulses/minute)

P_s = systolic pressure (mm Hg)

K_c = 7.73×10^{-4} liters/pulse-mm Hg

1. Systolic Pressure (P_s) and Diastolic Pressure (P_d)

$$P_s = \left[0.5\ f_3(CO_2) + 120\right]\ f_3(O_2) + f_1(D) + P_m$$

$$P_d = \left[0.0835\ f_3(CO_2) + 120\right]\ f_3(O_2) - 40 + f_2(D) + P_m$$

where P_m = manual pressure input (mm Hg)

$f_n(D)$ = drug levels as follows

$$f_1(D) = 3.0\ V_{e1} + 12.78\ V_{e2} - \left[6.25\ A + 26\ (A - 1.5)\right]$$

$$f_2(D) = 1.0\ V_{e1} + 6.42\ V_{e2} - \left[3\ A + 22.5\ (A - 1.5)\right]$$

V_{e1} = effective concentration of ephedrine (mg)

V_{e2} = effective concentration of methoxamine (mg) $0 \leq (A - 1.5)$

A = relative anesthesia level

2. Pulse Rate (P_r)

$$P_r = \left[70 + 0.286\ f_3(CO_2)\right]\ f_3'(O_2) + f_3(D) + R_m$$

where

R_m = manual-pulse-rate input (pulses/minute)

$$f_3'(O_2) = 1 + 2.14\left[f_3(O_2) - 1\right]$$

$$f_3(D) = 1.48\ V_{el} - 2.76\ V_{e2} - 10.96\ (A - 1.5)$$

J. ANESTHESIA LEVEL (A)

$$A = K_{n1}D_{eno} + K_{p1}D_{ep} + K_{cy3}D_{ecy}$$

$$K_{n1} = 0.5 \times 10^{-3}\ \frac{1}{\text{mm Hg}}$$

$$K_{p1} = 0.91 \times 10^{-2}\ \frac{1}{\text{mg}}$$

$$K_{cy3} = 0.149 \times 10^{-1}\ \frac{1}{\text{mg}}$$

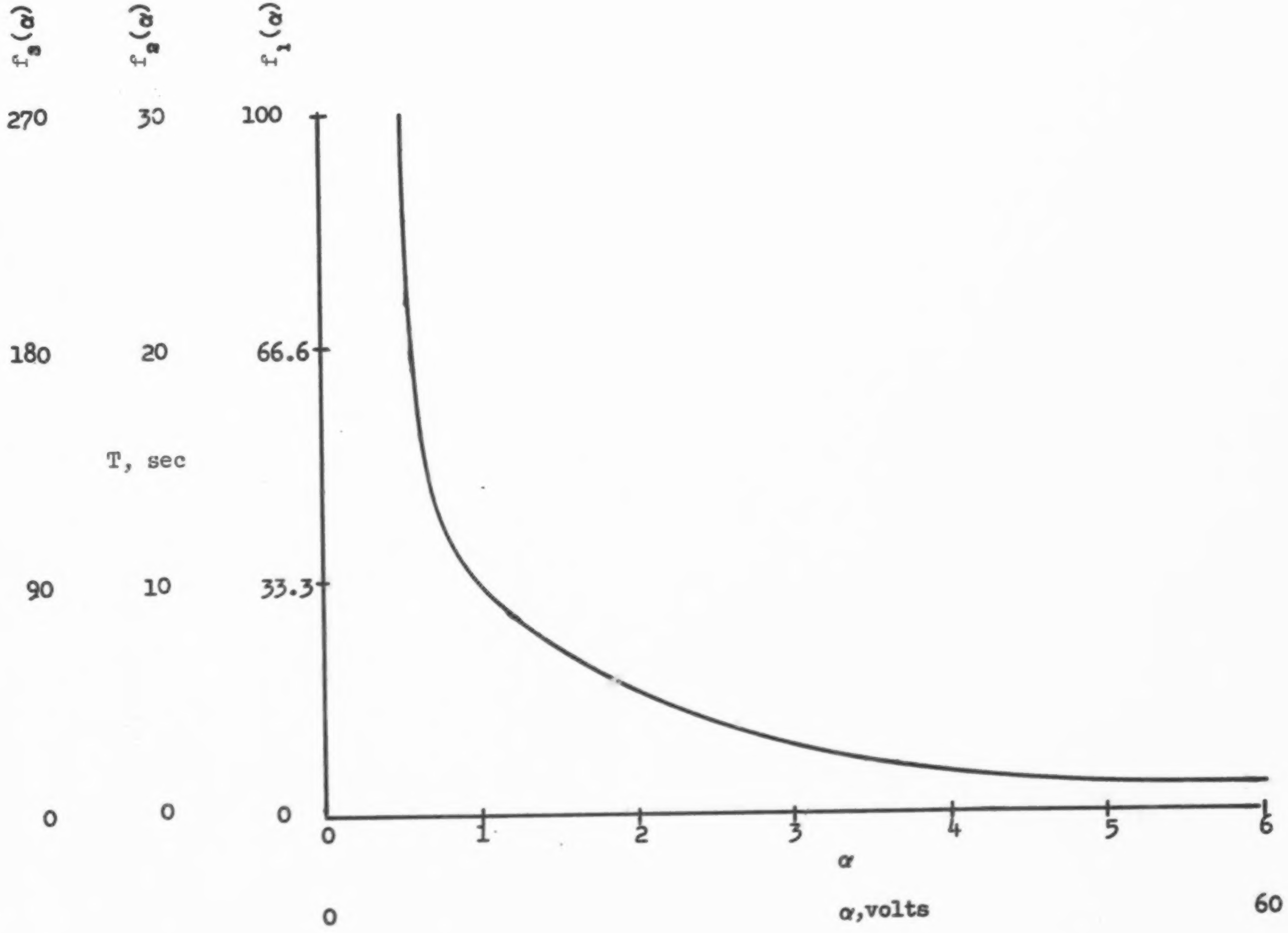
K. BREATHING PARALYSIS

To stop breathing,

$B_a = B_r = 0$ when $A = 2.5$ and remains zero until $A < 2.3$

or

$B_a = B_r = 0$ for $D_{es} \geq 22$ mg and remains zero until $D_{es} < 11$ mg.



Time Constant for CO_2 Concentration as a Function of $\alpha = f(V_r, C)$

Figure I-1

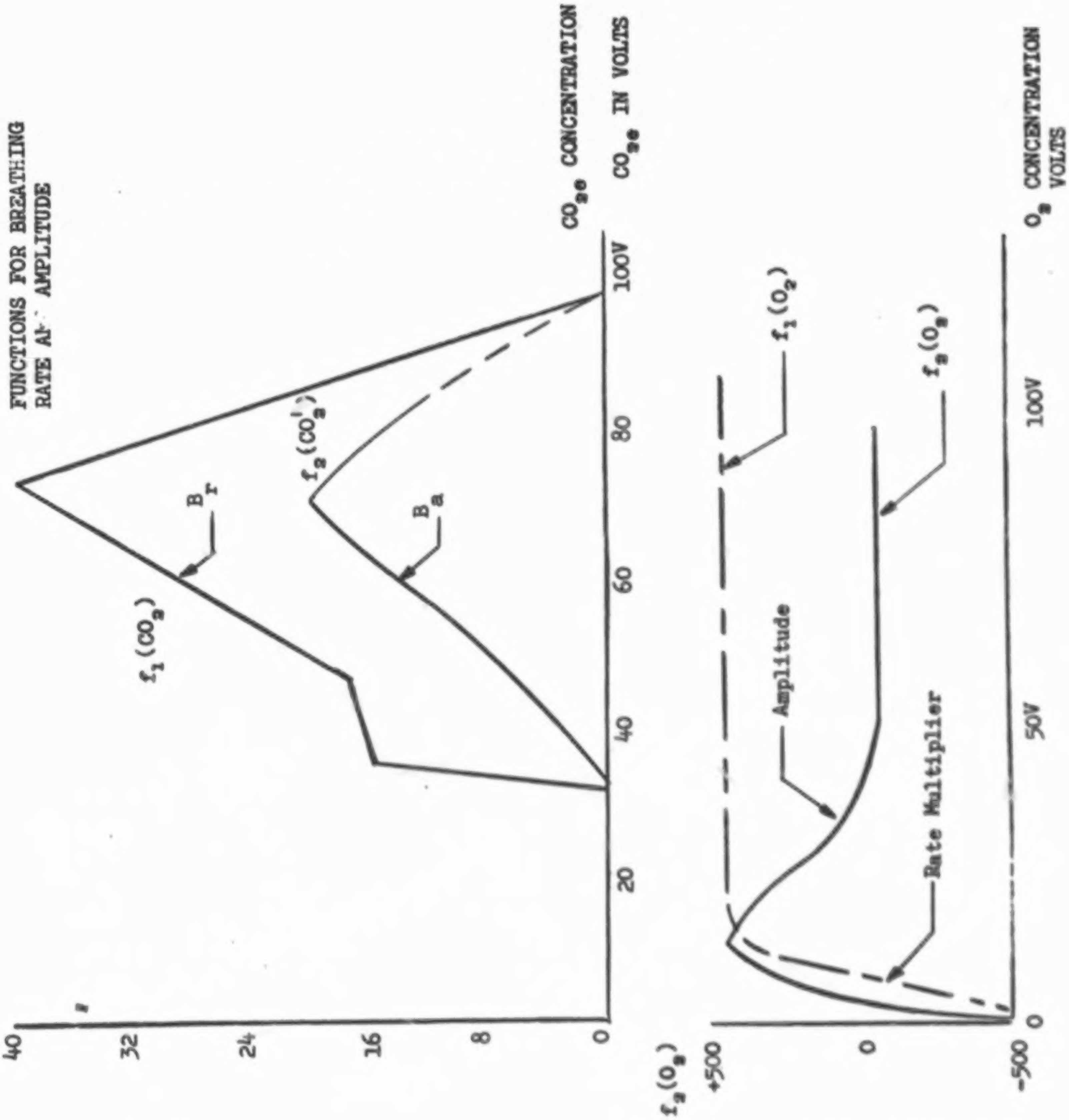
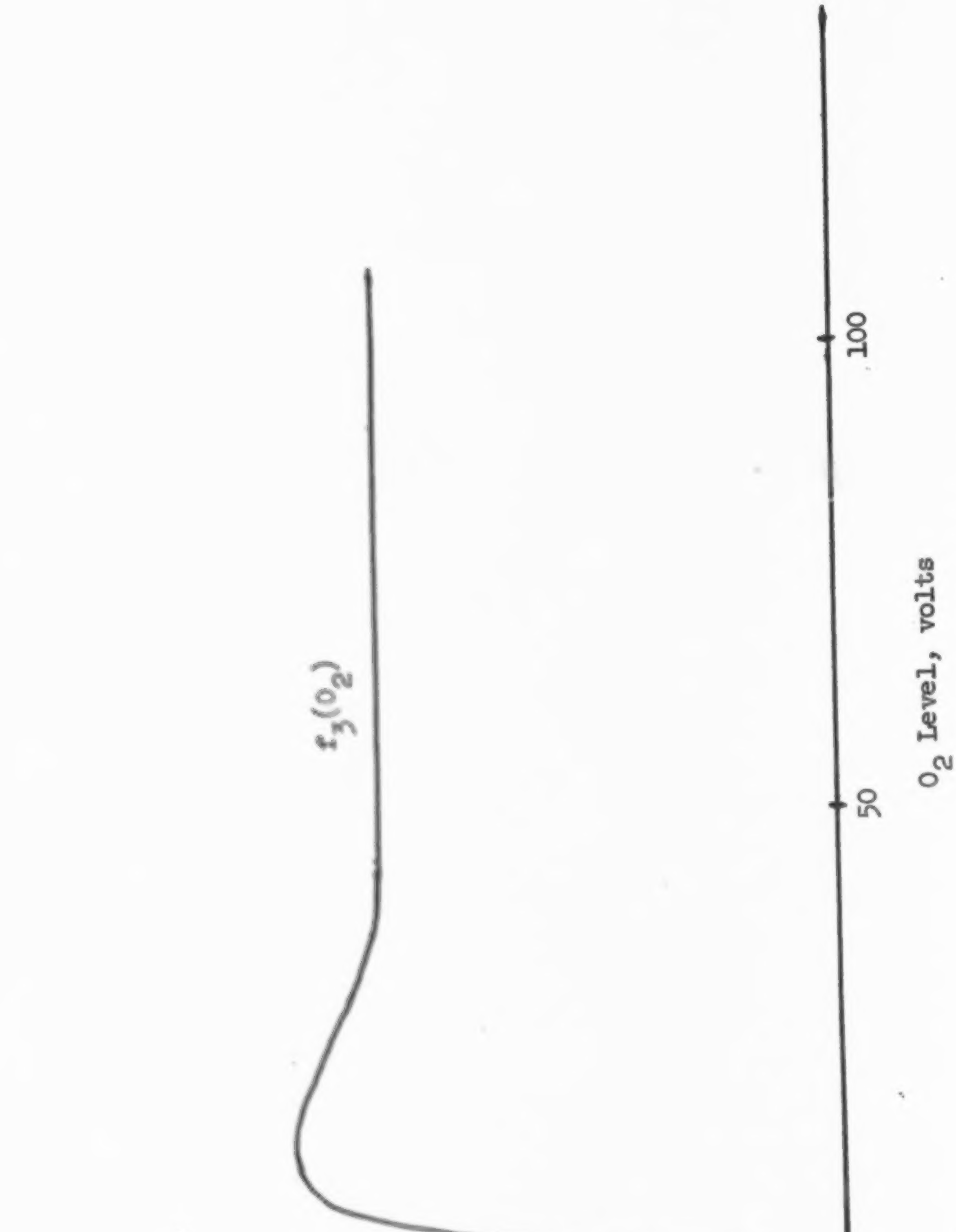
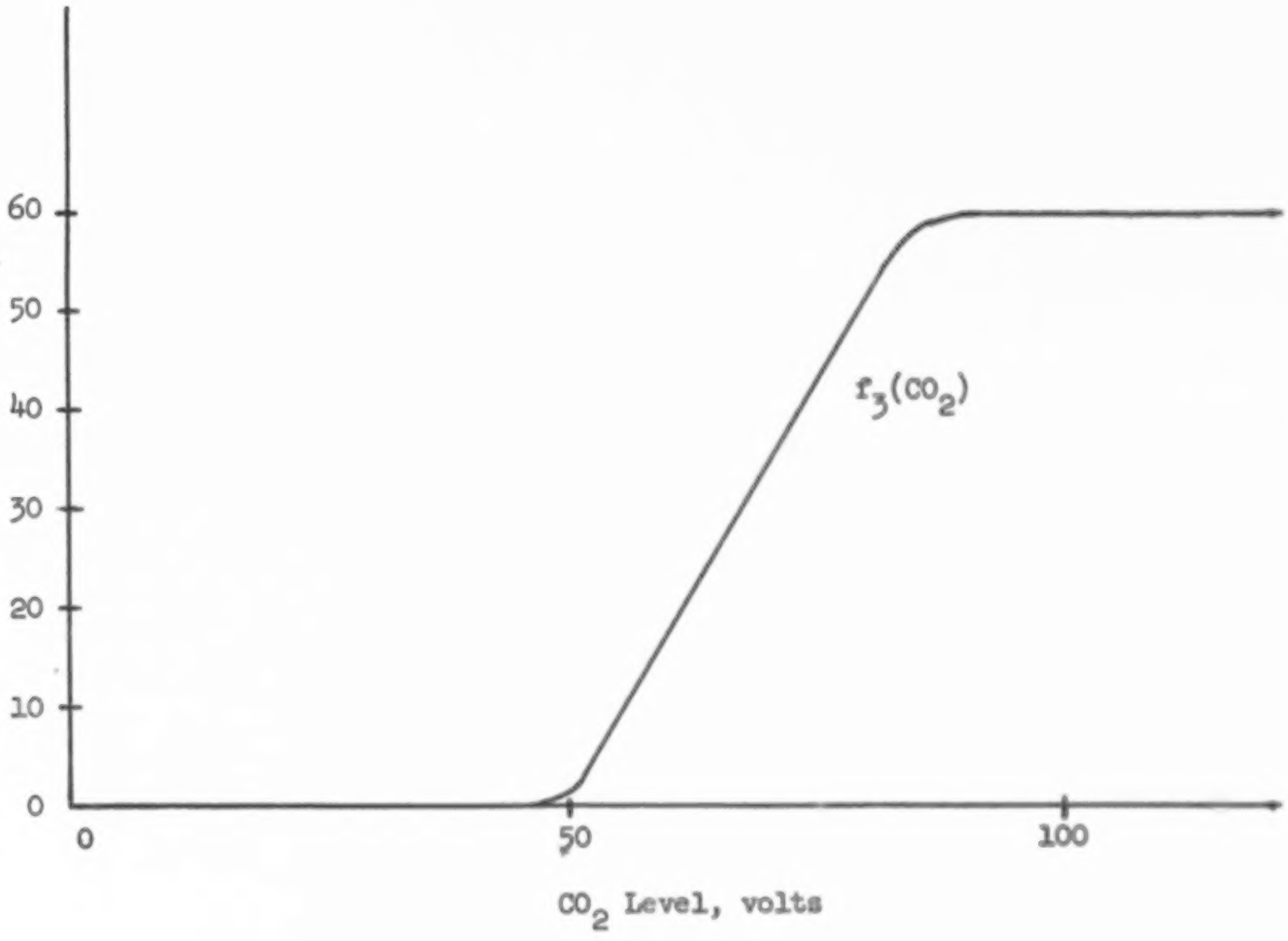

FUNCTIONS FOR BREATHING RATE AND AMPLITUDE
BREATHING VOLUME (LITERS), B_a
RATE (BREATHS/MINUTE), B_r
0
1
2
3
4
0
8
16
24
32
40
$f_1(CO_2)$
B_r
$f_2(CO_2')$
B_a
20
40
60
80
100V
CO_{2e} CONCENTRATION
CO_{2e} IN VOLTS
BREATHING-RATE MULTIPLIER
$f_1(O_2)$
0
0.5
1
VOLUME CHANGE IN MILLILITERS
$f_2(O_2)$
-500
0
+500
Amplitude
Rate Multiplier
$f_1(O_2)$
$f_2(O_2)$
0
50V
100V
O_2 CONCENTRATION VOLTS

Figure I-2



Oxygen-Modifier Function

Figure I-3



Blood-Pressure Change as a Function of CO_2 Level

Figure I-4

APPENDIX II

SIGNIFICANT ANALOG RUNS

Strip-chart-recorder traces showing time-varying, simulated-patient reactions to inputs, based on empirical equations developed in Appendix I, are presented on succeeding pages in ten pairs of multiple plots that reflect the more significant runs in an analog-computer simulation. Normal values are plotted at the beginning of the curves. Each pair of traces was run simultaeously and represents the combined results of the indicated actions.

From top to bottom, the first of each pair (1A, 2A, etc.) shows (a) systolic blood pressure; (b) diastolic blood pressure; (c) pulse rate; (d) effective concentration of Pentothal in the viscera (i.e., the amount assumed active in causing the reaction); (e) the combined effective dosage of Vasopressors 1 and 2, which affect blood pressure identically while No. 1 elevates the pulse rate and No. 2 depresses it; (f) blood circulation; (g) CO_2 level in the blood; and (h) effective concentration of N_2O in the viscera (i.e., the amount assumed active).

The second of each pair (1B, 2B, etc.) shows, from top to bottom, (a) modified CO_2 level, which reflects drug modifications; (b) effective O_2 level in the tissues; (c) breathing rate as computed by the model; (d) breathing amplitude as computed by the model; (e) ventilation rate (i.e., product of computed breathing rate and amplitude and a suitable constant), which is valid as long as the student induces no aided ventilation and no lung blockages occur; (f) anesthesia level, a composite summation of the effective dosages of all anesthesia drugs in the viscera; (g) effective dosage of succinylcholine, or the amount assumed effective in inducing relaxation; and (h) effective concentration of cyclopropane in the viscera (i.e., amount assumed active).

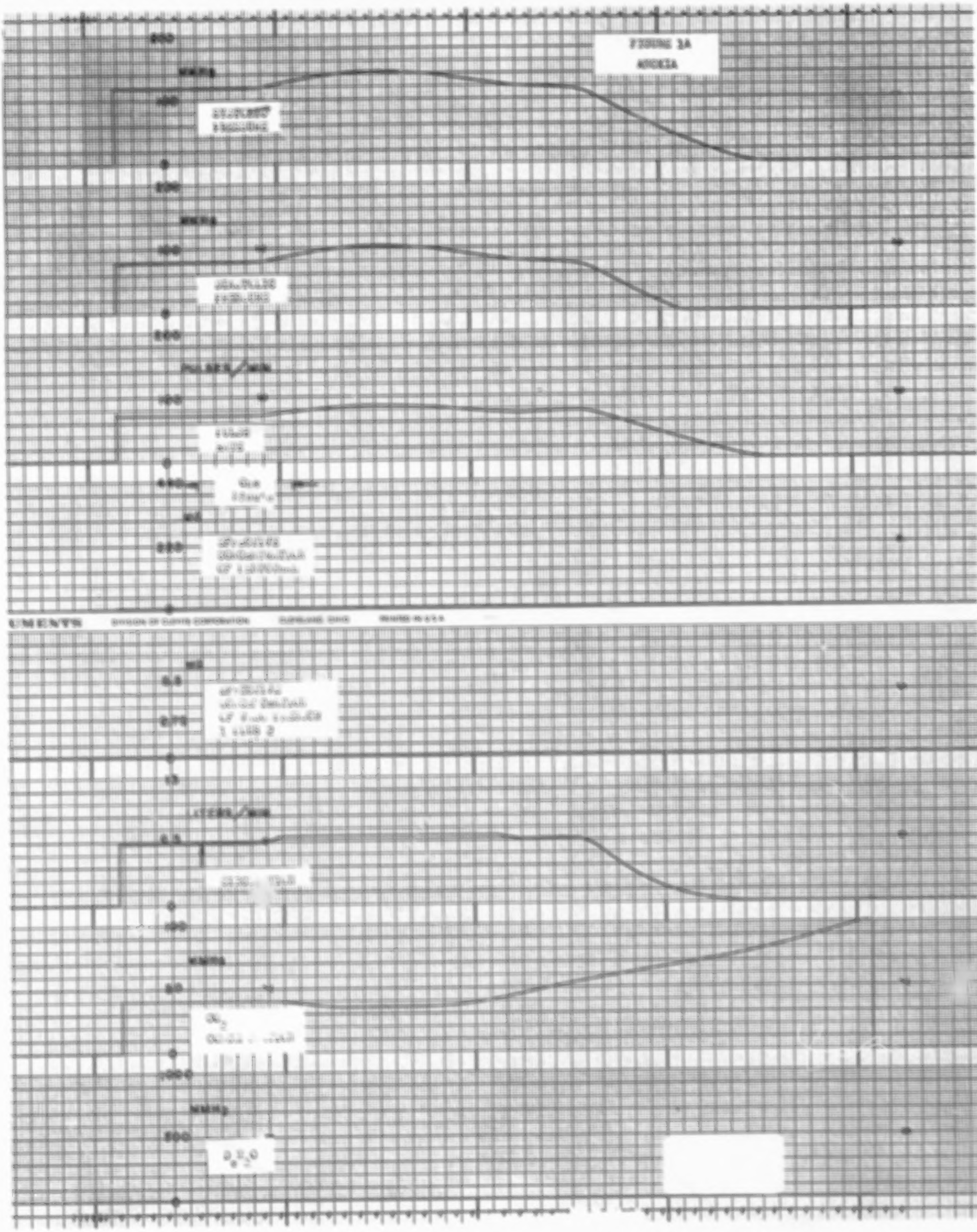


FIGURE 3A
ANOXIA
200
MMHg
100
0
PULSES/MIN
ML
LITERS/MIN
MMHg
80
1000
500

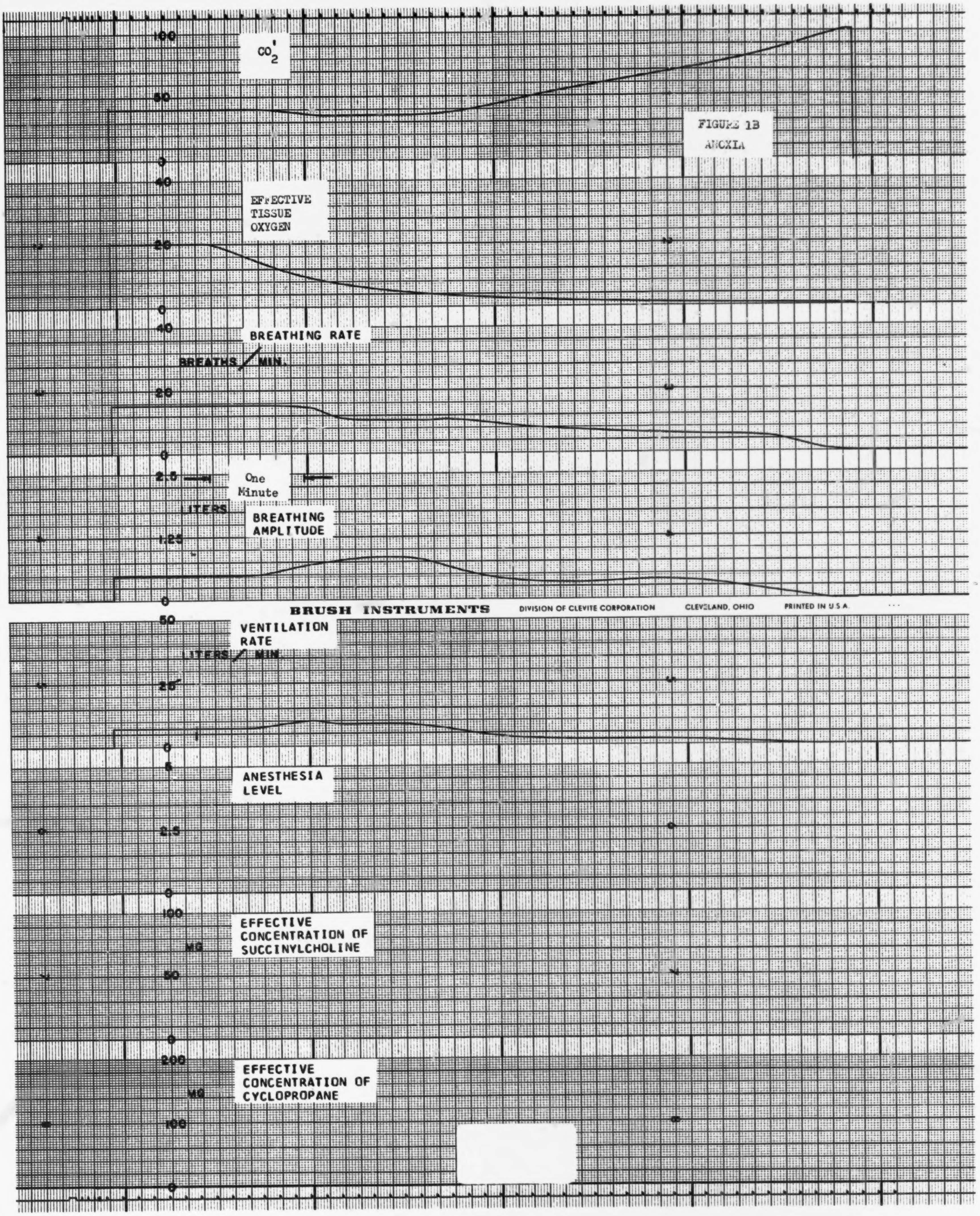


FIGURE 1B
ANOXIA

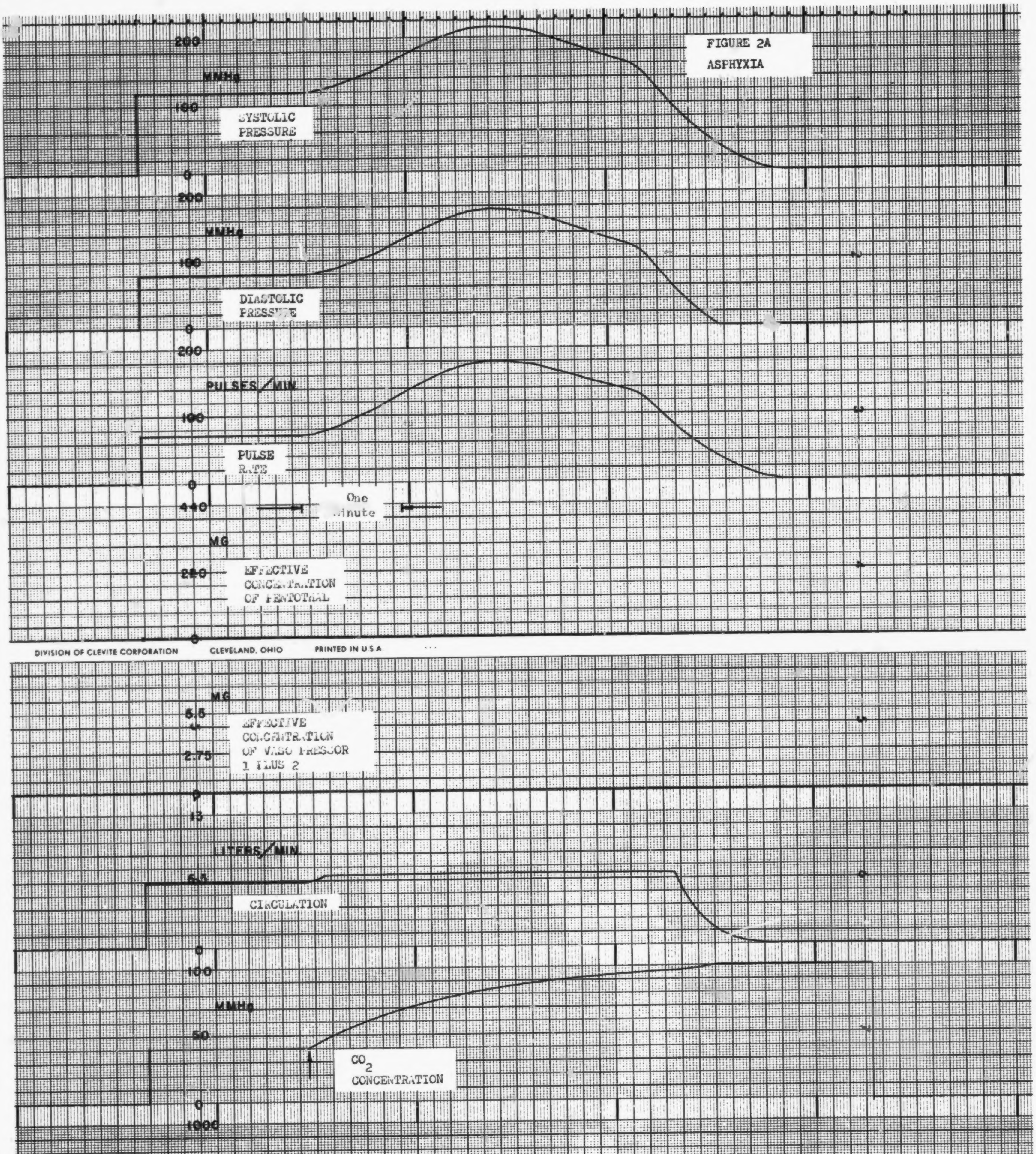


FIGURE 2A
ASPHYXIA

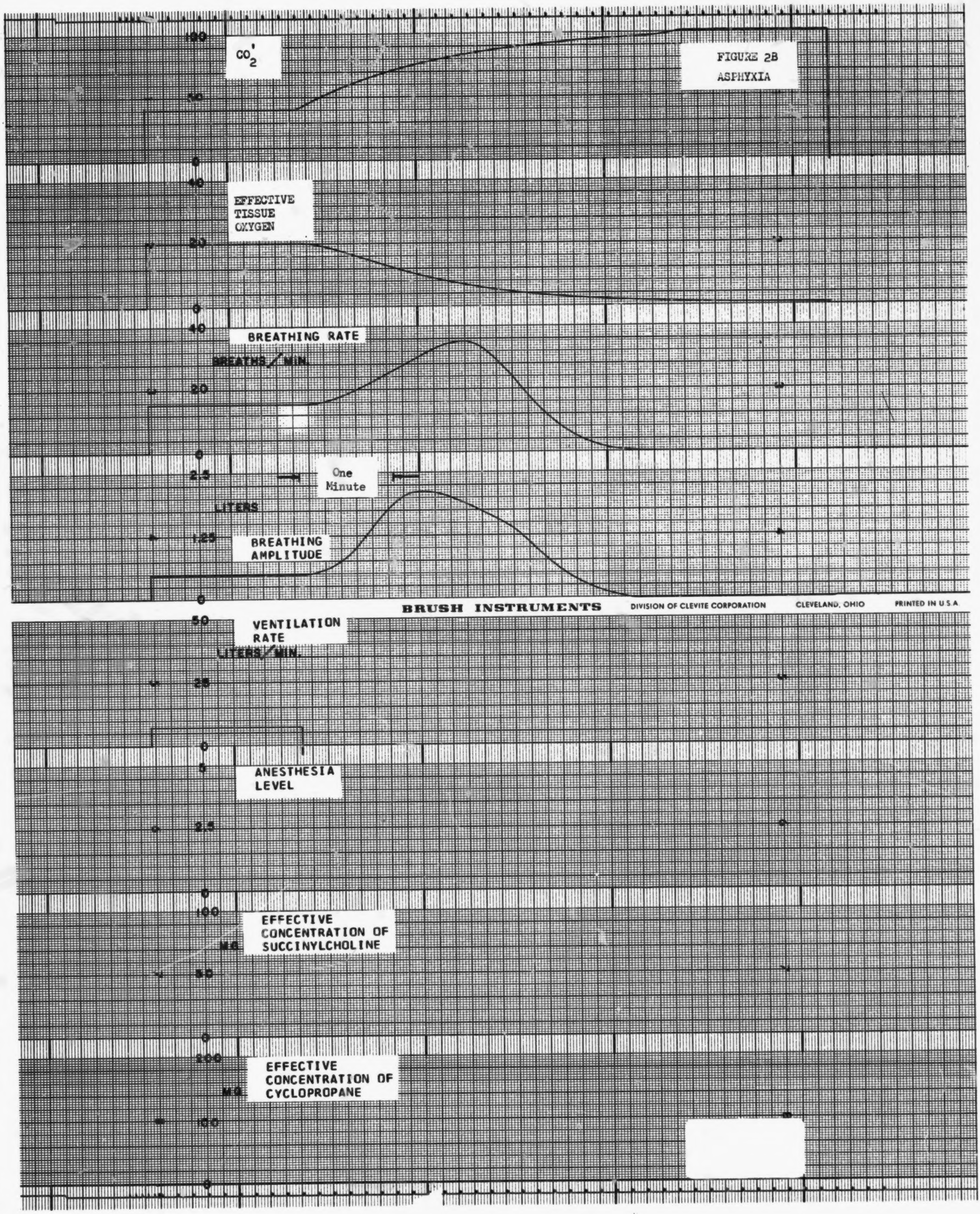


FIGURE 2B
ASPHYXIA

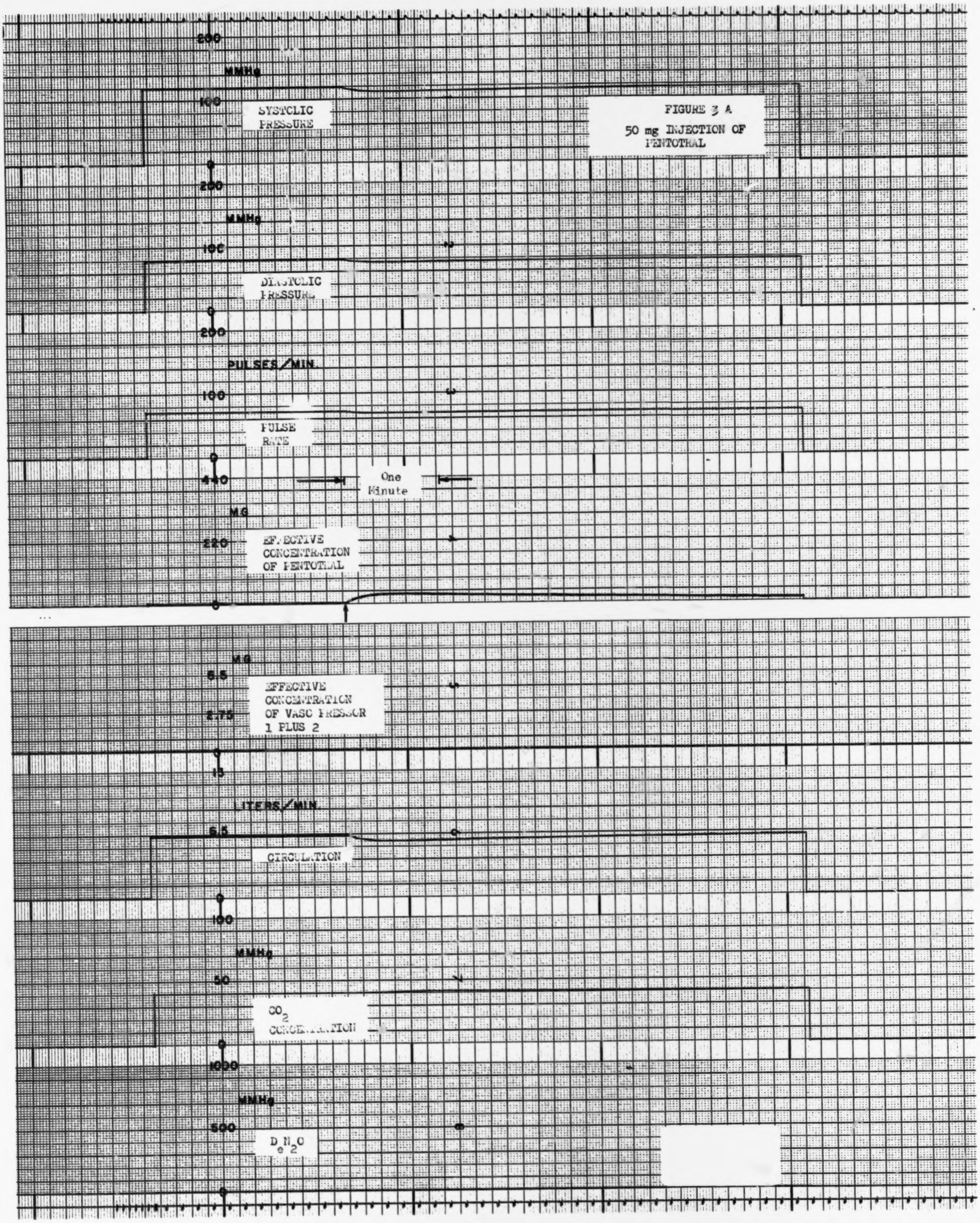


FIGURE 3 A

50 mg INJECTION OF PENTOTHAL

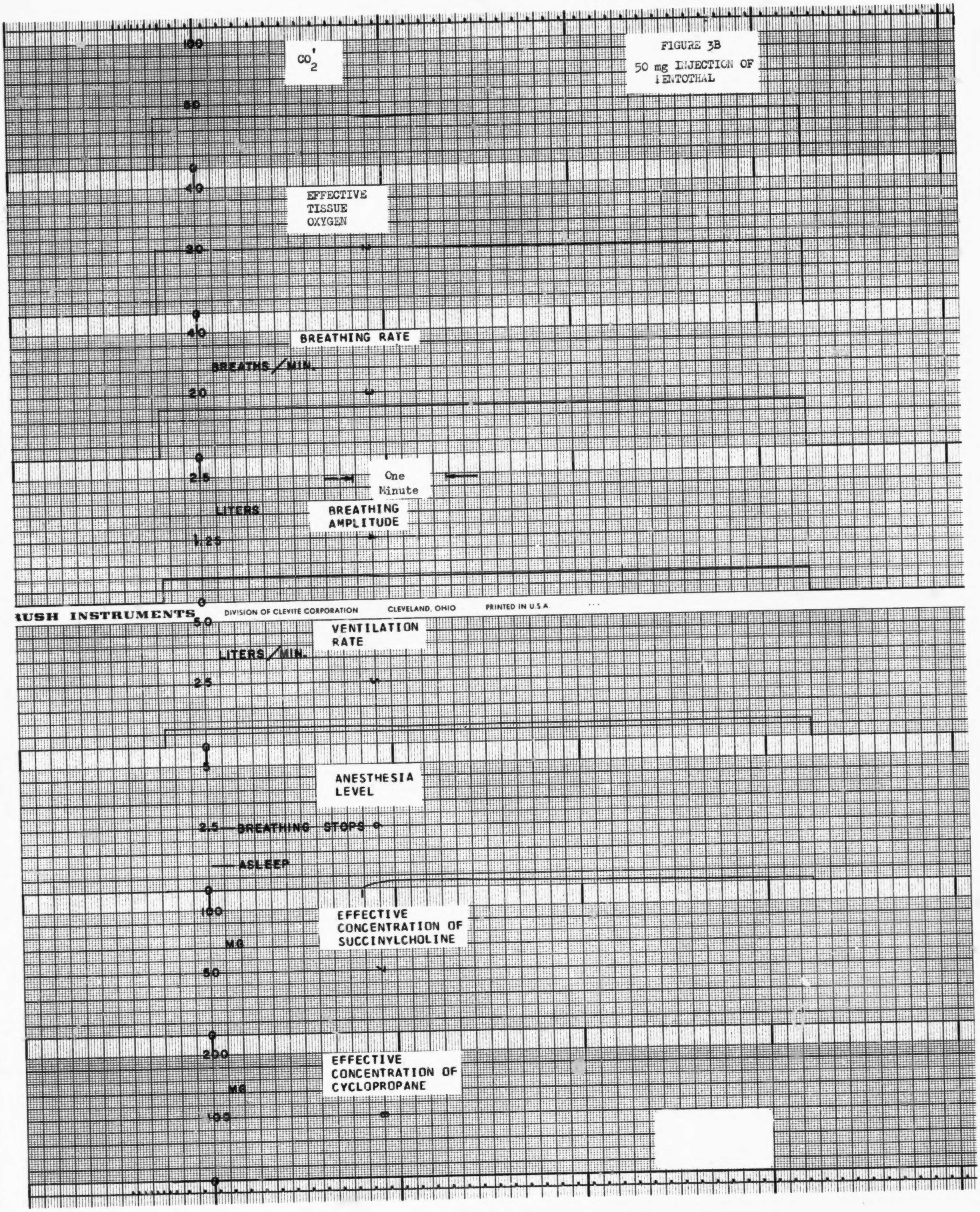


FIGURE 3B
50 mg INJECTION OF PENTOTHAL

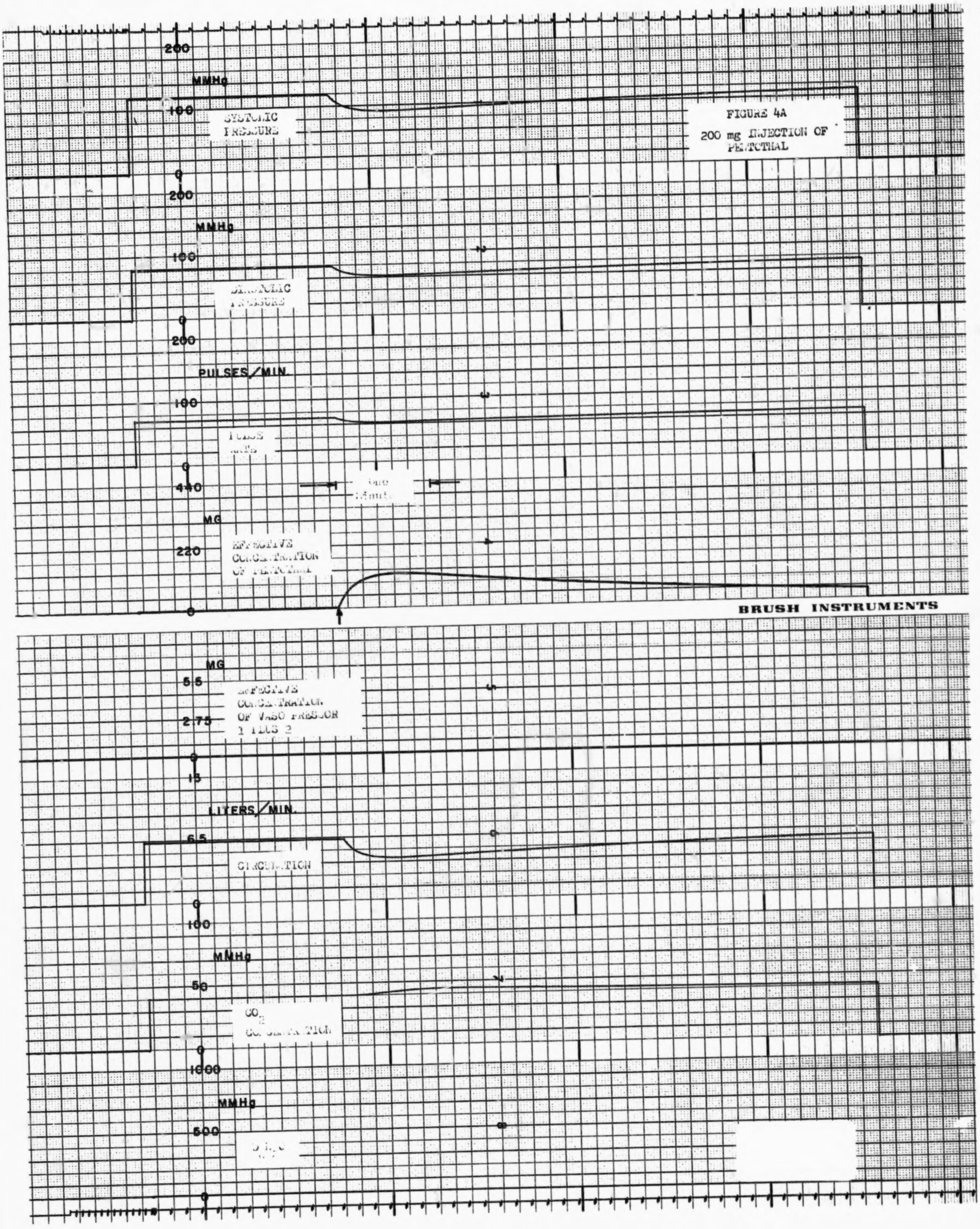
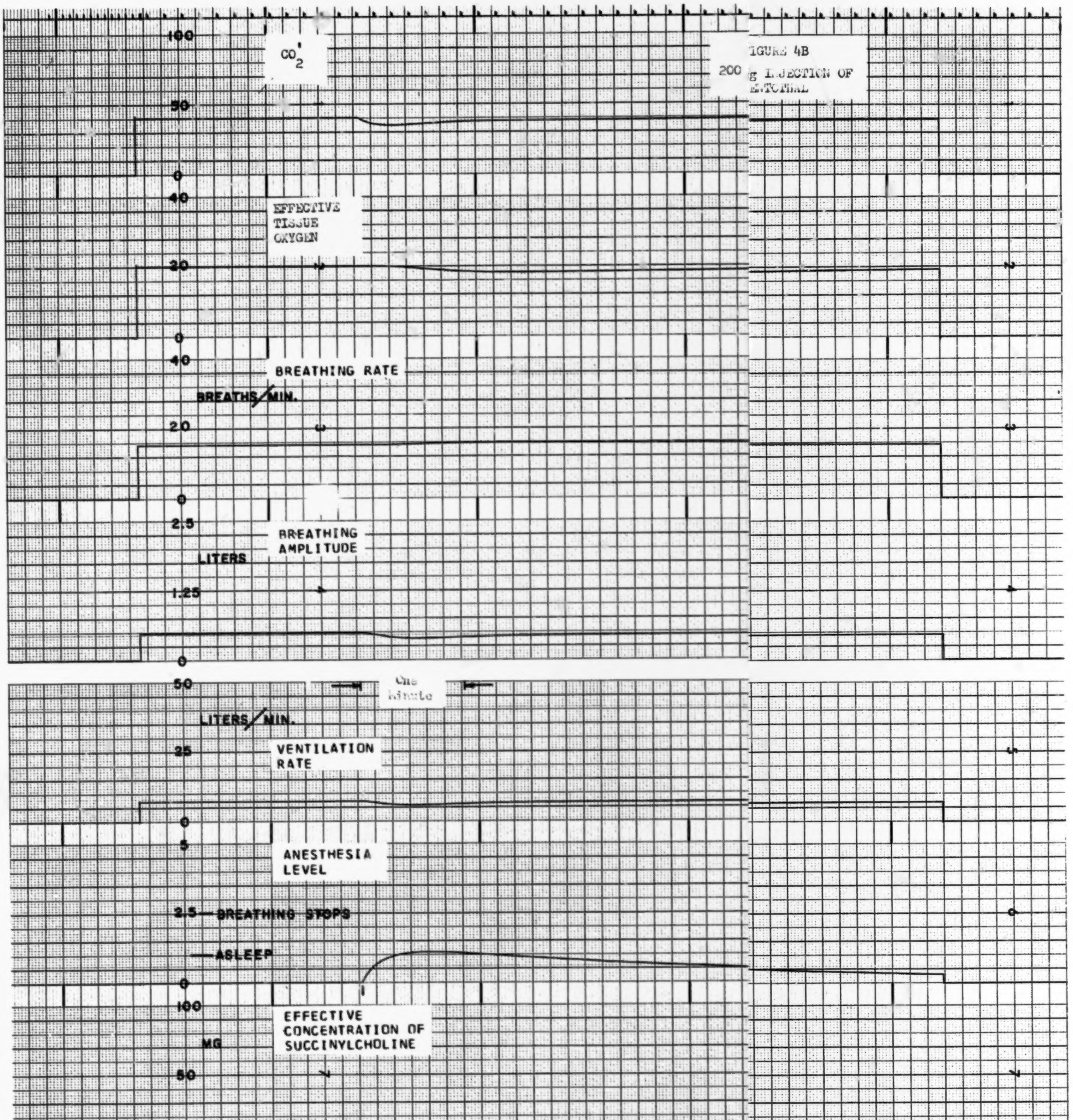


FIGURE 4A

200 mg INJECTION OF PENTOTHAL


IGURE 4B
200 g INJECTION OF
ENTOTHAL
100
CO'2
50
0
40
EFFECTIVE TISSUE OXYGEN
20
0
40
BREATHING RATE
BREATHS/MIN.
20
0
2.5
BREATHING AMPLITUDE
LITERS
1.25
0
50
One Minute
LITERS/MIN.
VENTILATION RATE
25
0
5
ANESTHESIA LEVEL
2.5 — BREATHING STOPS
— ASLEEP
0
100
EFFECTIVE CONCENTRATION OF SUCCINYLCHOLINE
MG
50
0
200
EFFECTIVE CONCENTRATION OF CYCLOPROPANE
MG
100
0

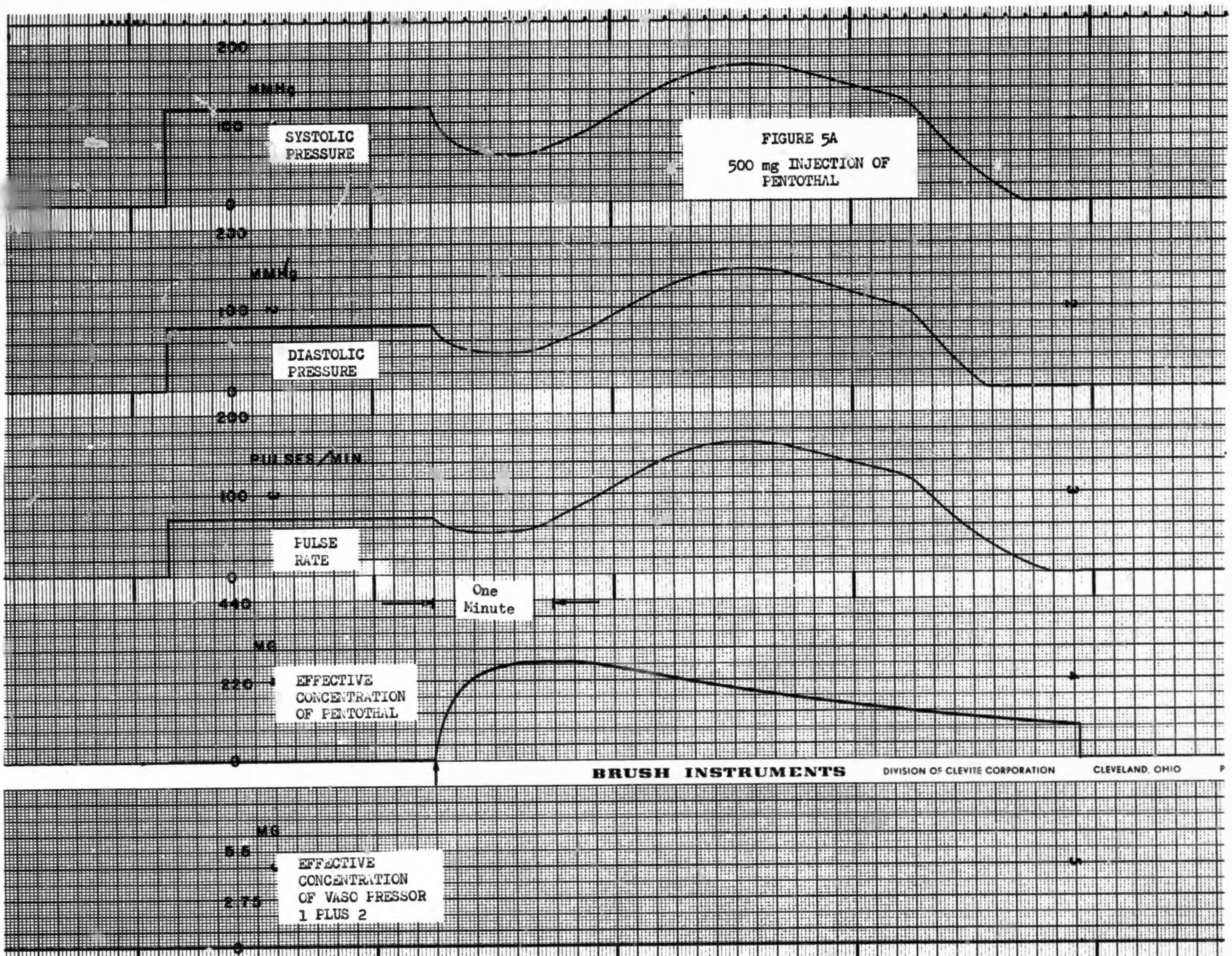


FIGURE 5A

500 mg INJECTION OF PENTOTHAL

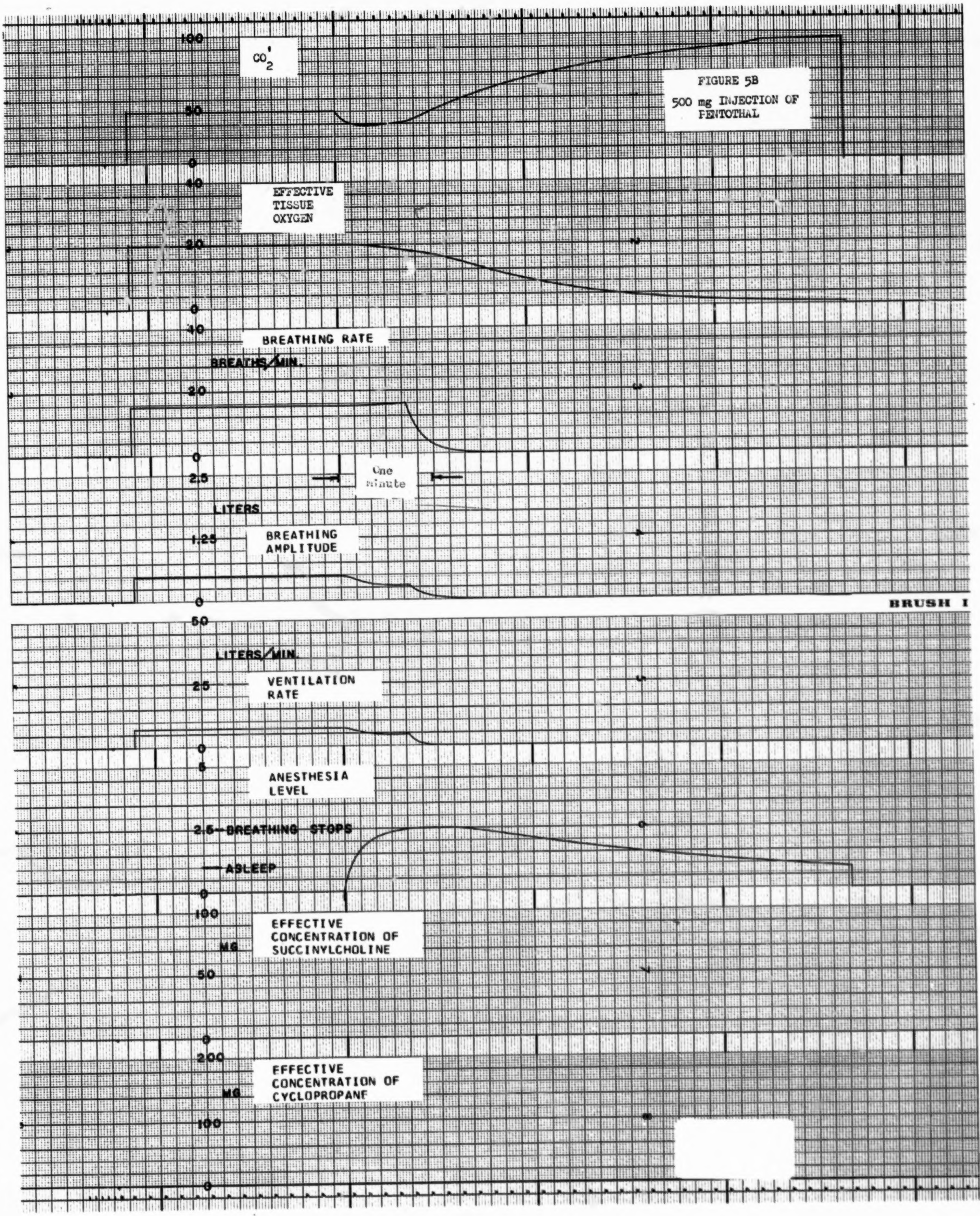


FIGURE 5B
500 mg INJECTION OF PENTOTHAL

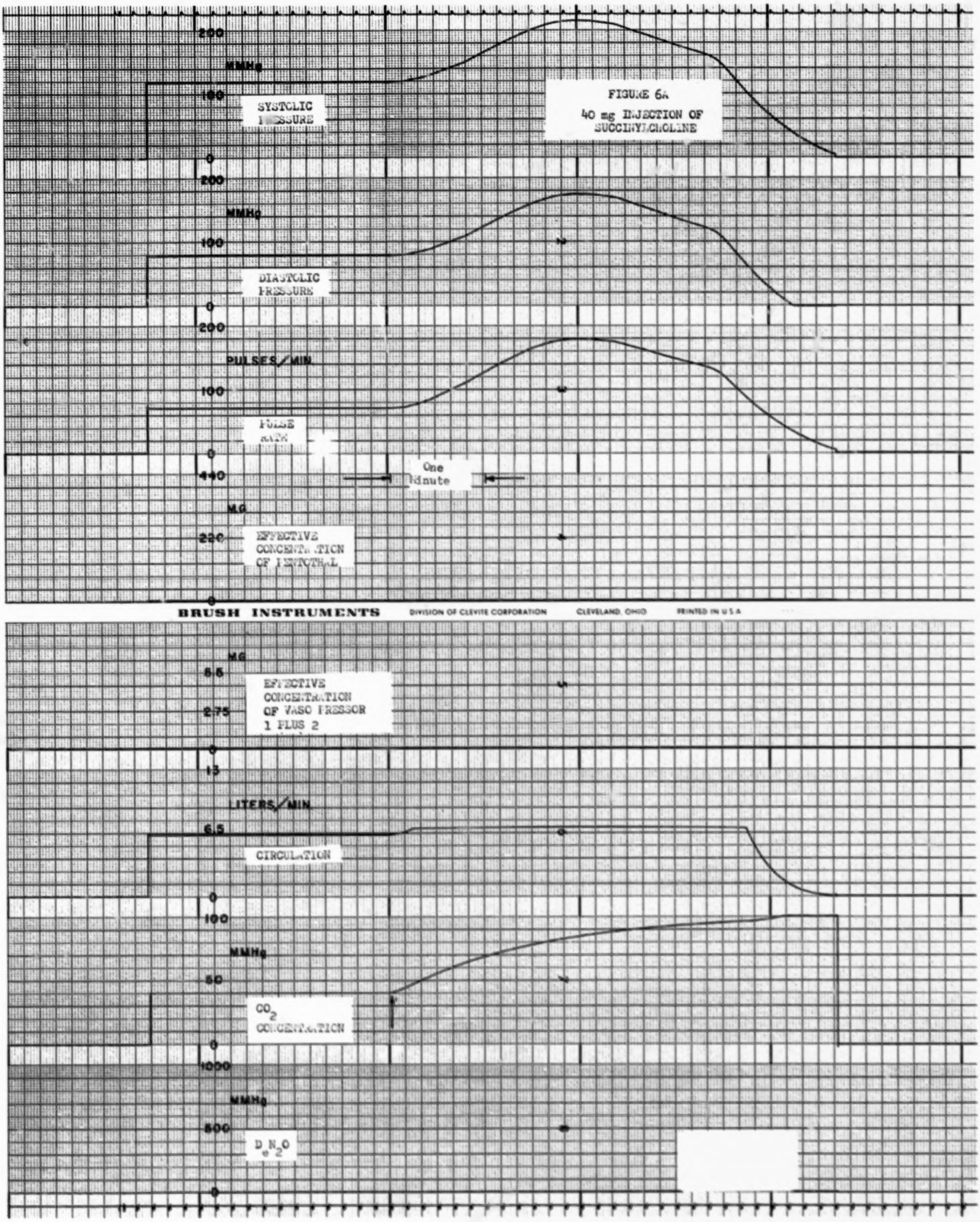


FIGURE 6A
40 mg INJECTION OF SUCCINYLCHOLINE

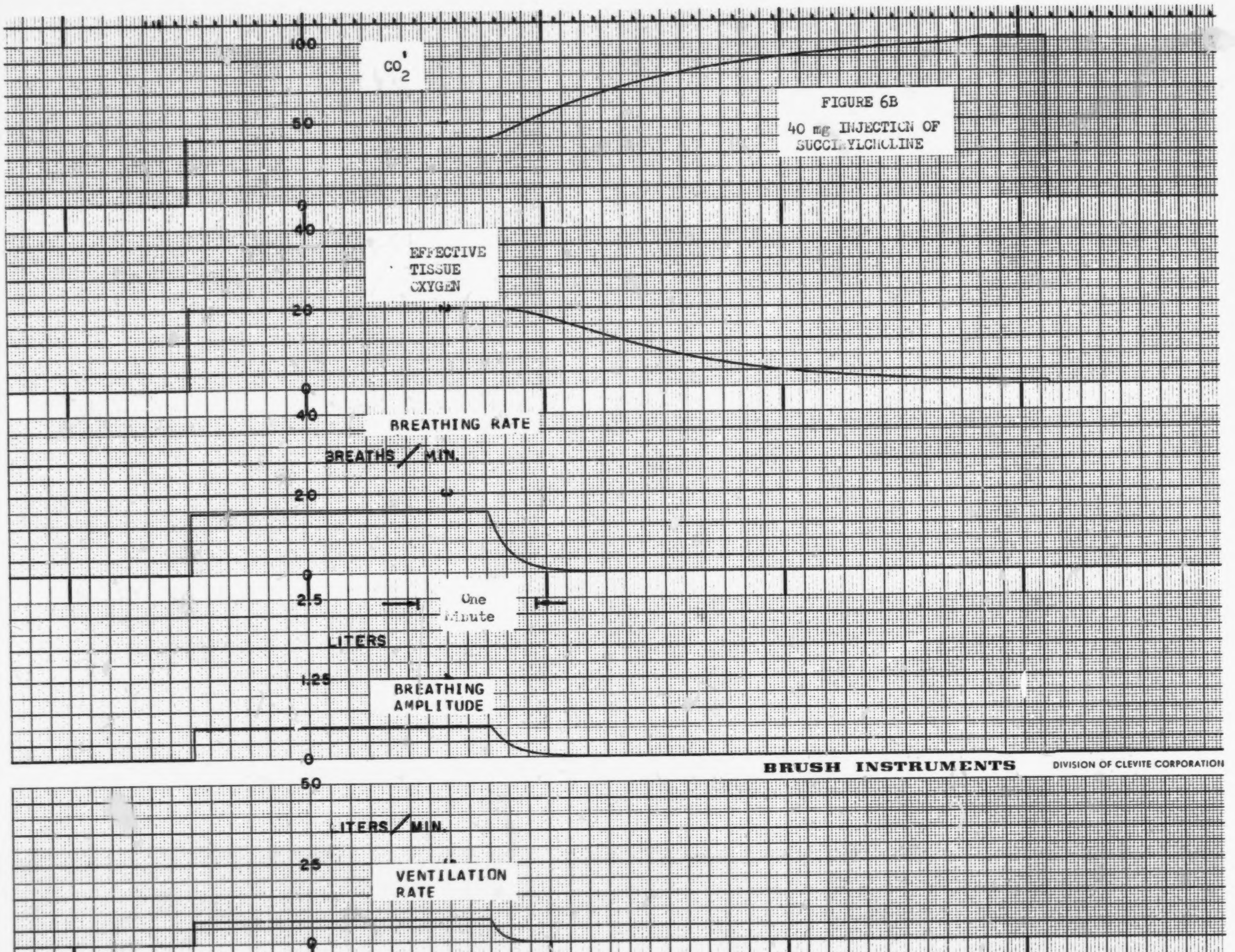


FIGURE 6B
40 mg INJECTION OF SUCCINYLCHOLINE

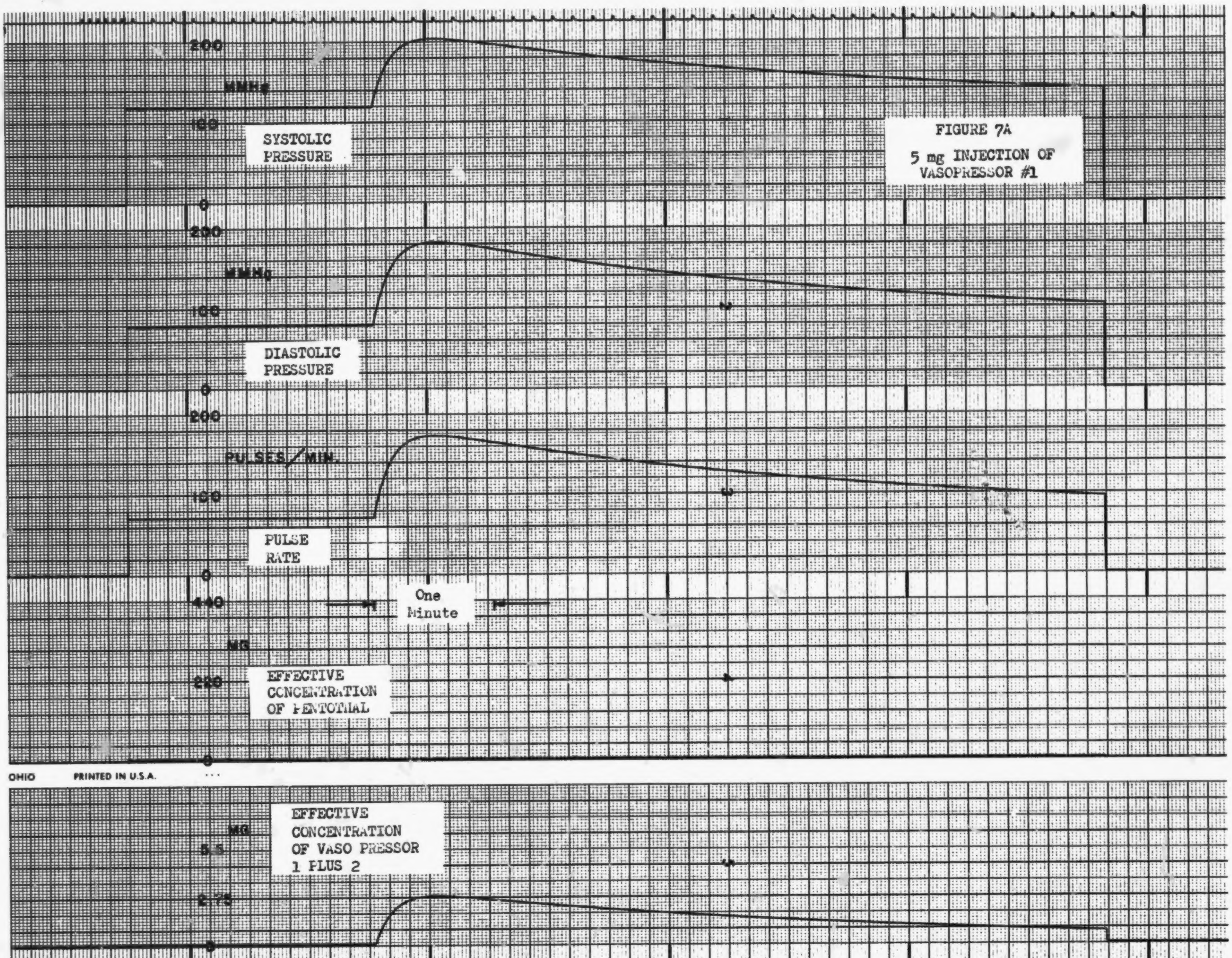


FIGURE 7A

5 mg INJECTION OF VASOPRESSOR #1

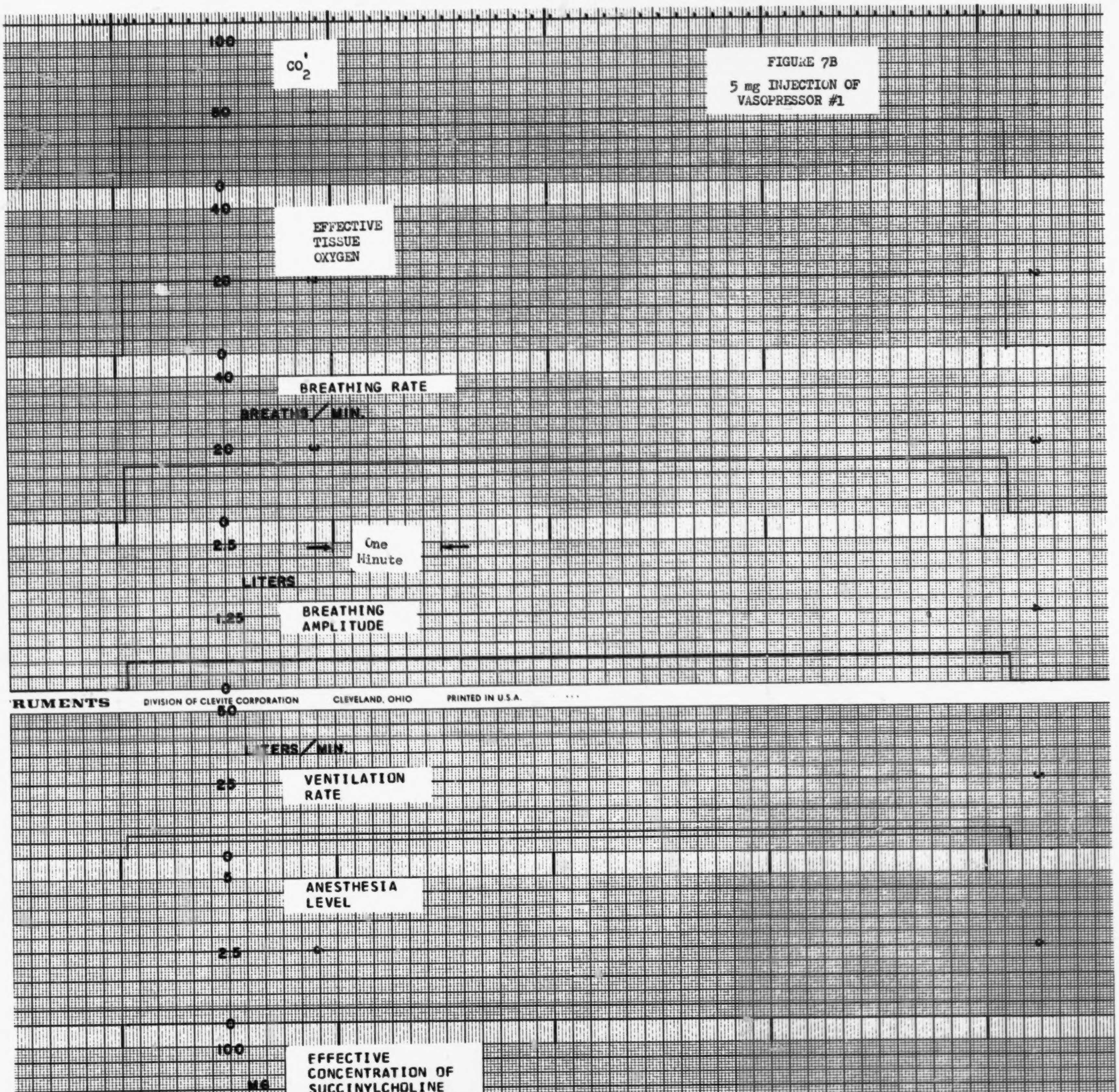


FIGURE 7B

5 mg INJECTION OF VASOPRESSOR #1

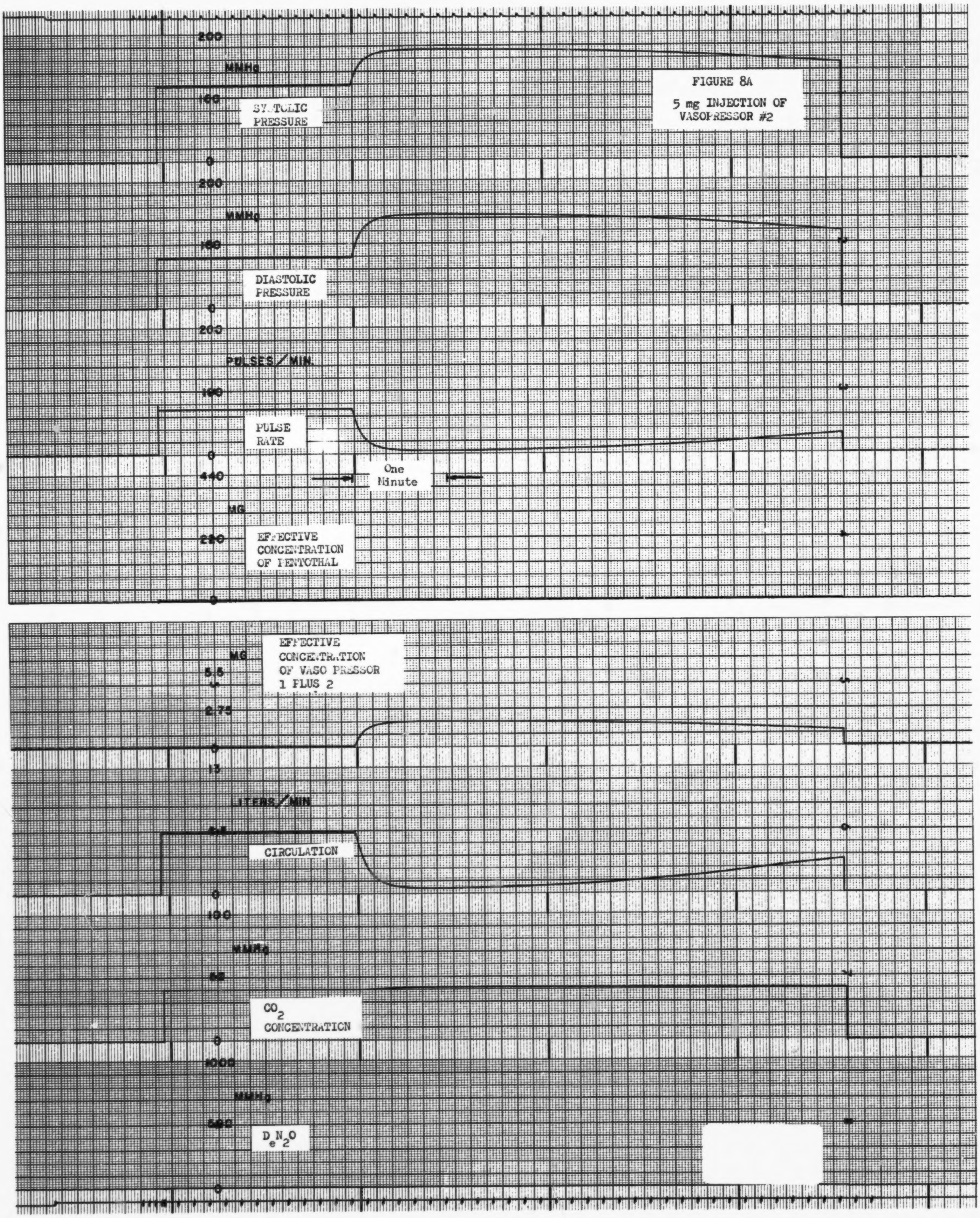


FIGURE 8A

5 mg INJECTION OF VASOPRESSOR #2

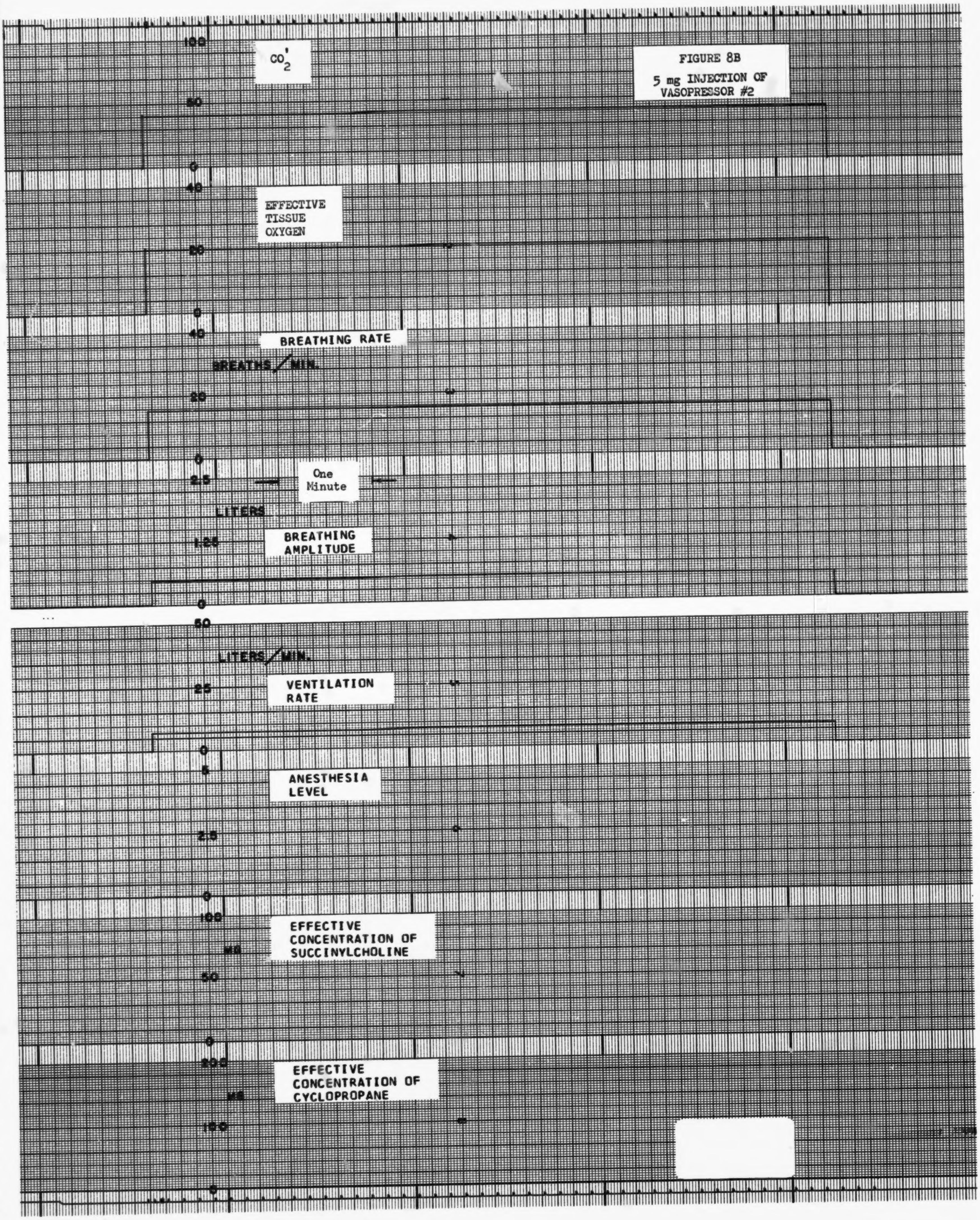


FIGURE 8B
5 mg INJECTION OF VASOPRESSOR #2

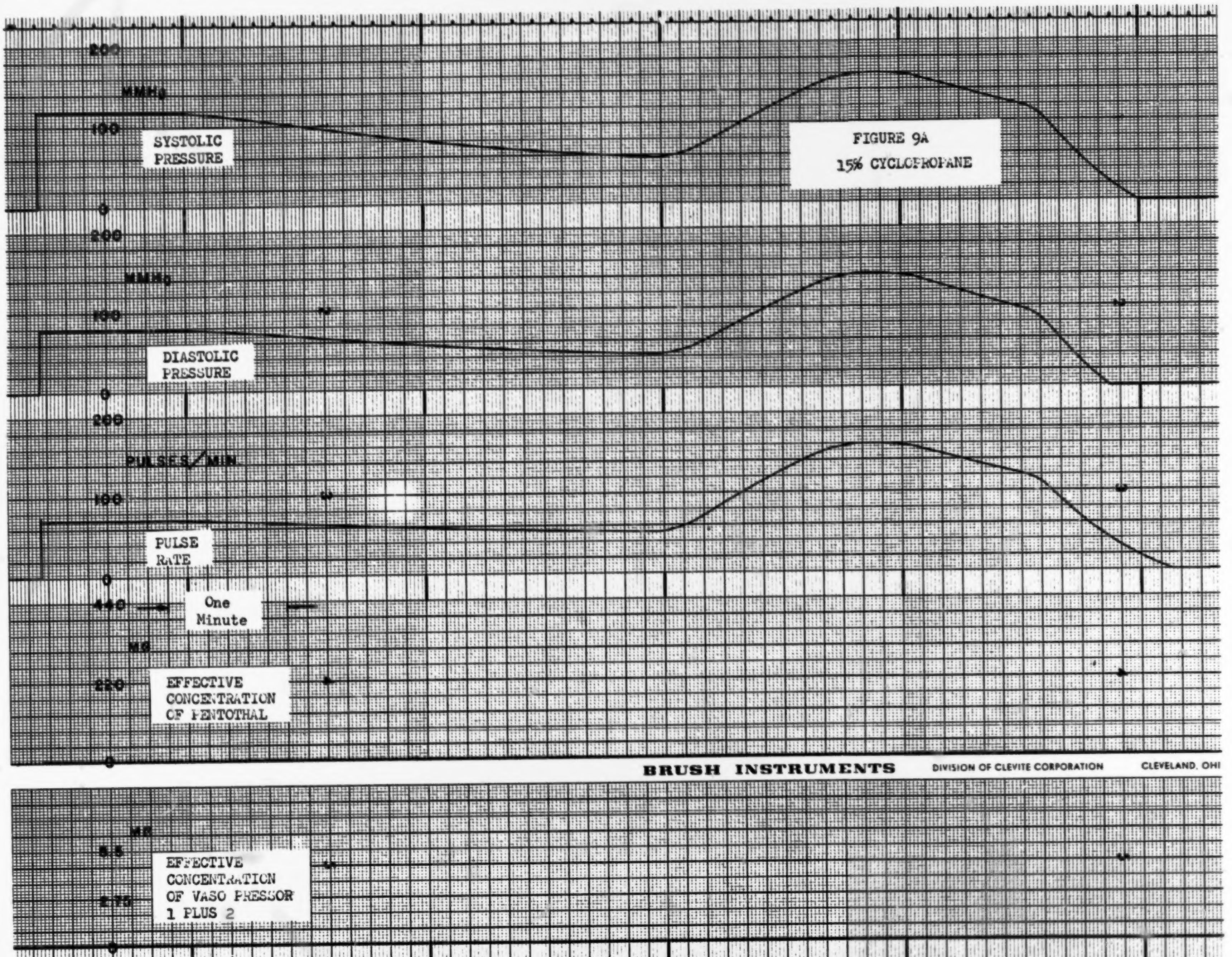


FIGURE 9A
15% CYCLOPROPANE

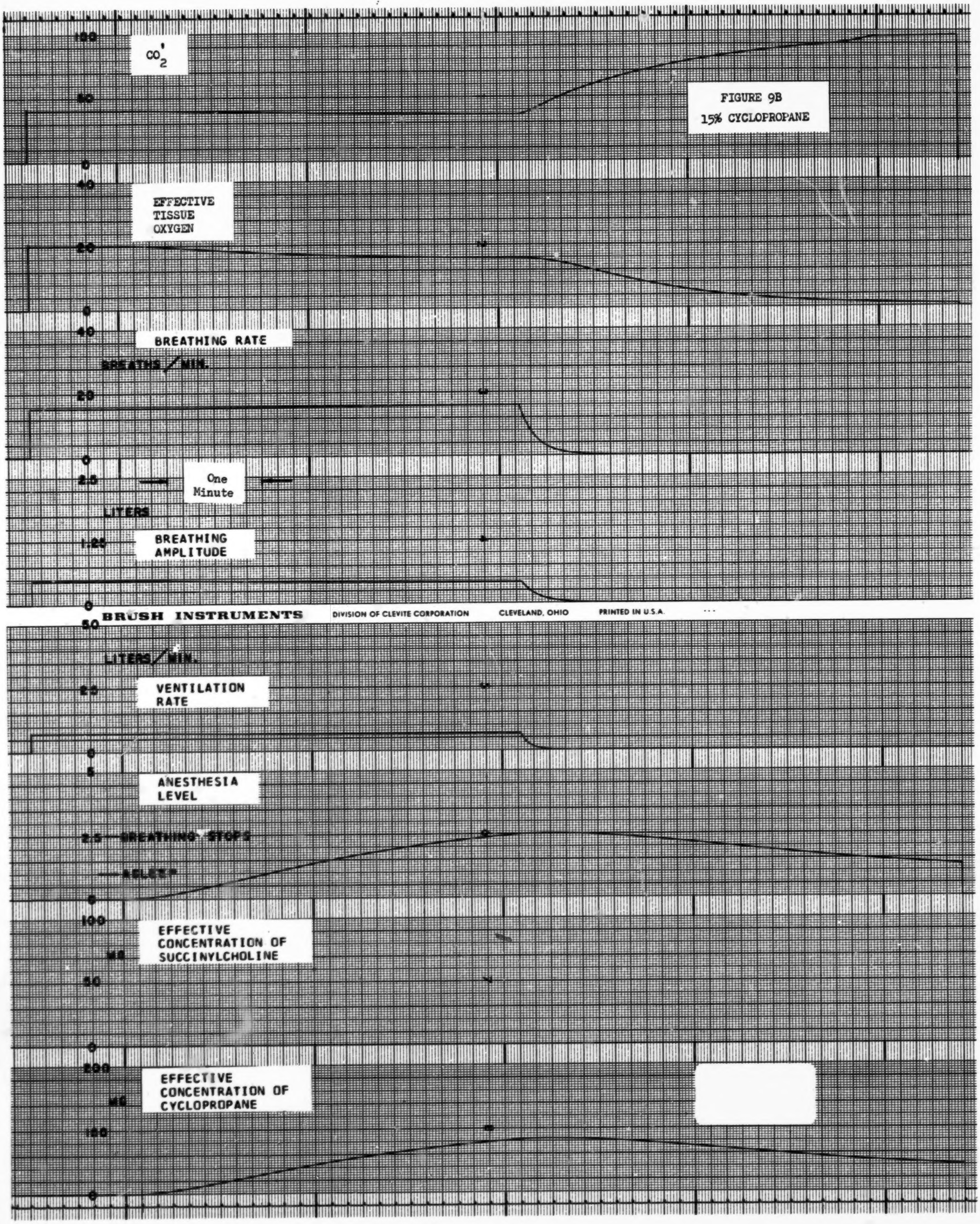


FIGURE 9B
15% CYCLOPROPANE

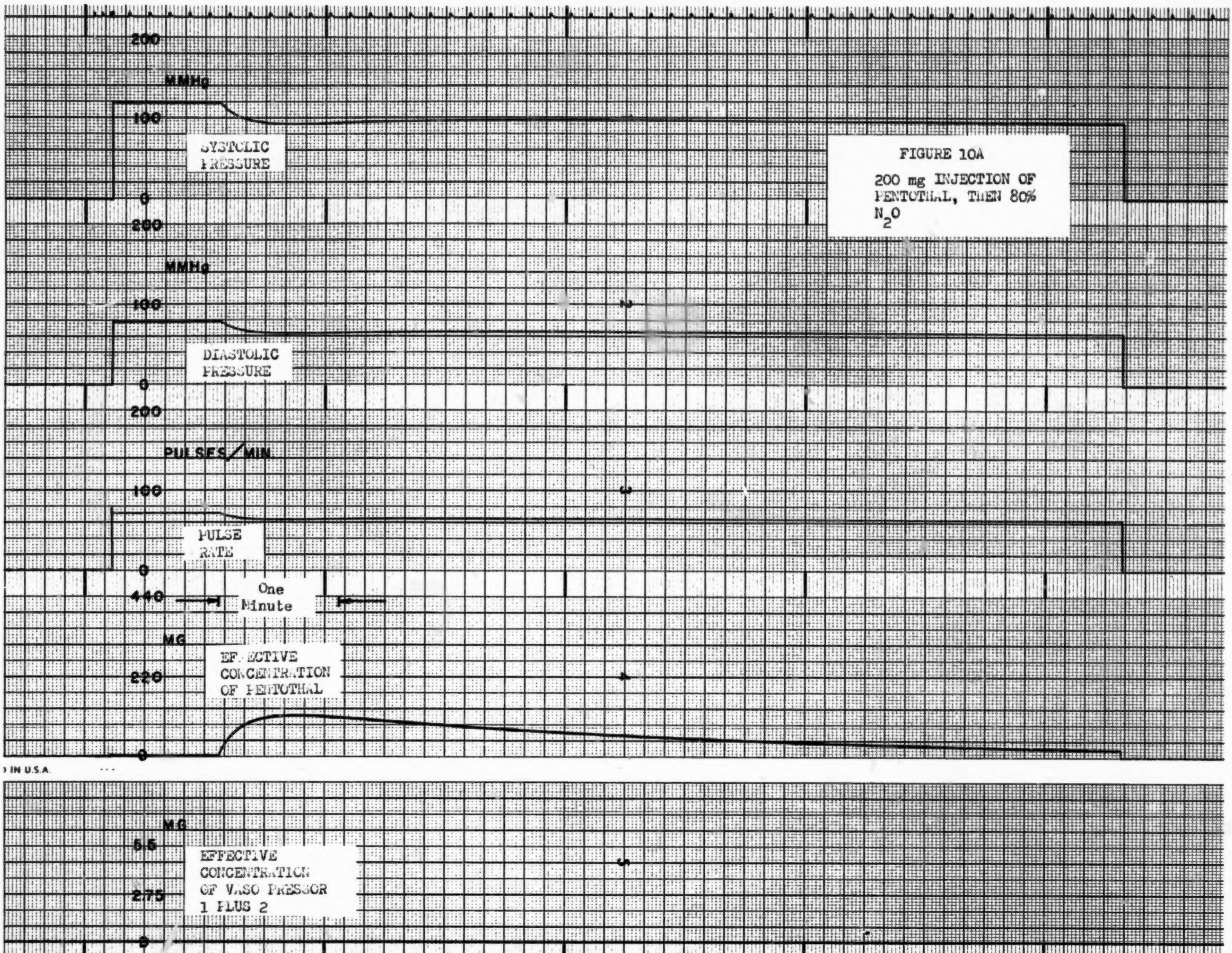


FIGURE 10A

200 mg INJECTION OF PENTOTHAL, THEN 80% N_2O

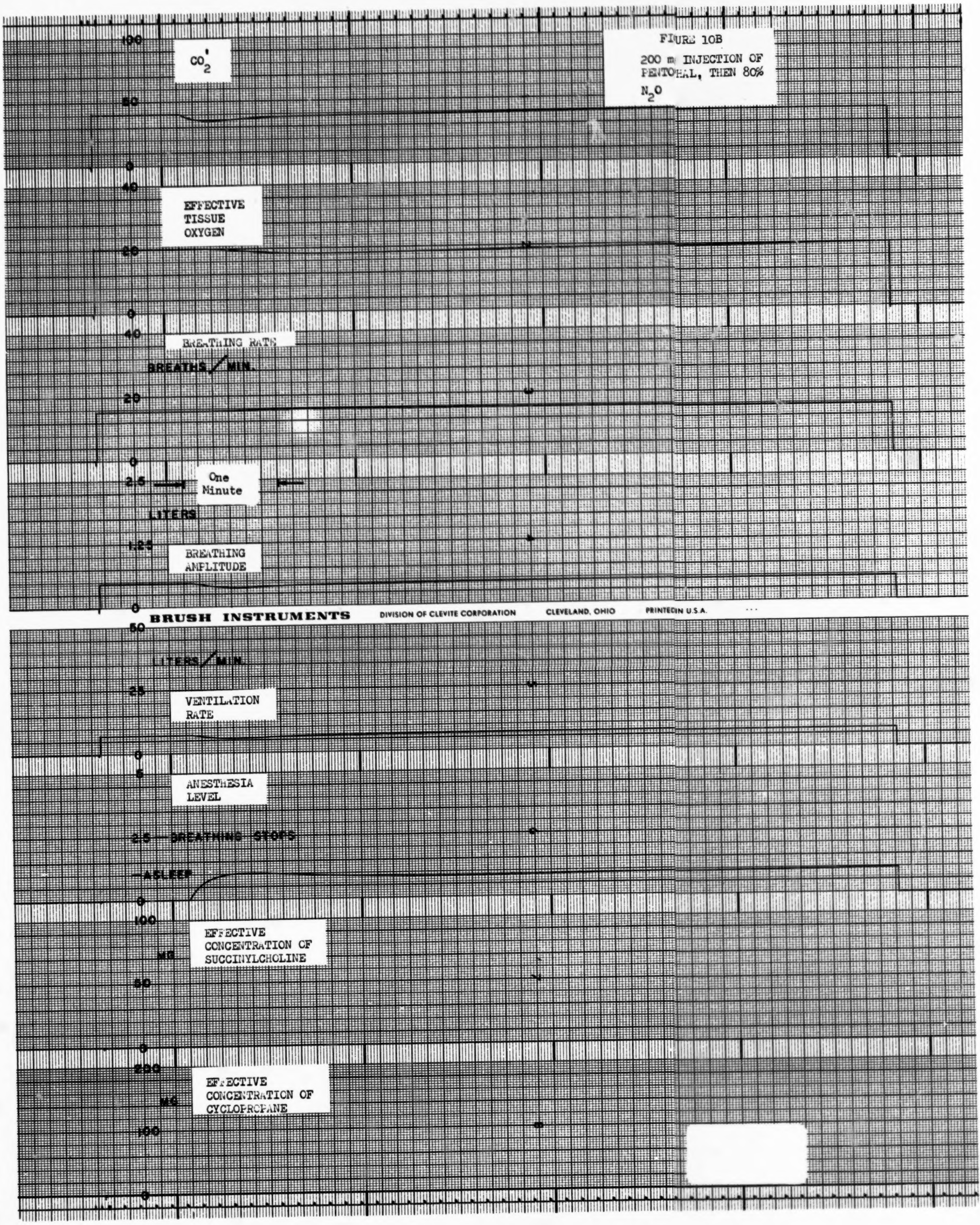


FIGURE 10B

200 mg INJECTION OF PENTOTHAL, THEN 80% N_2O

APPENDIX III

MANIKIN RESPONSES

A. MODIFICATIONS TO CALCULATED CIRCULATORY PARAMETERS

Systolic and diasystolic blood pressure and pulse rate have a step perturbation with a gradual linear dissipation over a 5-min interval (approximate) for (1) insertion of the airway, or (2) injection of succinylcholine without anesthesia ($A \leq 0.5$).

The size of the step depends on the anesthesia level (A) at the time of the stimulus:

For $A \leq 2.2$	For $A \geq 2.2$
$\Delta P_s = (80 - 36.3A)$	$\Delta P_s = 0$
$\Delta P_d = (40 - 18.2A)$	$\Delta P_d = 0$
$\Delta P_r = (60 - 27.2A)$	$\Delta P_r = 0$

where ΔP_s is the change in systolic pressure, ΔP_d the change in diastolic pressure, and ΔP_r the change in pulse rate. $A = 2.2$ can result from the injection of 400 mg of Pentothal or the accumulative equivalent of other anesthesia drugs. Subsequent doses will not affect the changes attributable to a previous stimulus, but will affect the step size (ΔP_s, ΔP_d, ΔP_r) resulting from subsequent stimuli.

During bucking, the same step-size perturbation occurs as described for intubation, and the 5-min tailoff does not start until the cessation of bucking.

Arrhythmia is keyed in automatically for all CO_2 levels above 80 mm Hg. If the arrhythmia is manually started by the instructor, the CO_2 level must be below or at 40 mm Hg for it to stop.

B. PHYSICAL-CONTROL PARAMETERS AS A FUNCTION OF ANESTHESIA LEVEL (A)

1. Jaw Tension (T_j)

$$T_j = a_{FS}(1.0 - 0.2A)\left(1 - \frac{D_{es}}{22}\right)\left[f_1(O_2)\right]$$

where a_{FS} is the full-scale amplitude of the control signal and D_{es} the effective concentration (mg) of succinylcholine in the viscera.

2. Eyelid Tension (T_e)

$$T_e = a_{FS}\left(\frac{A}{0.275}\right) \text{ for } A \leq 0.275$$

$$T_e = \left[1 - (A - 0.275)(0.3)\right] a_{FS} \text{ for } 0.275 \leq A \leq 2.6$$

$$T_e = 0.66\, a_{FS} \text{ for } A > 2.6 \text{ or for } D_{es} \geq 11 \text{ mg}$$

$T_e = a_{FS}$ for sensitive reaction to airway or laryngoscope (see Section C, below)

Manikin blinks for $A < 0.092$.

3. Pupil-Dilation Signal (D_e)

$$D_e = 4\left[\frac{1.33}{0.33 + f_1(O_2)}\right] \text{ for } A < 0.5$$

$$D_e = (4.5 - A)\left[\frac{1.33}{0.33 + f_1(O_2)}\right] \text{ for } A \geq 0.5$$

$$2 \leq D_e \leq 8 \text{ mm}$$

4. Vocal Cords

For $A < 0.55$ and $D_{es} < 11$ mg,

$$L_C = 0.5\, a_{FS}$$

where L_C represents the vocal-cord-control signal. For $A > 0.55$ or $D_{es} > 11$ mg,

$L_C = 0$

For bucking or laryngospasm stimulation,

$L_C = a_{FS}$

5. Aryepiglottic-Fold Signal (F_c)

$F_C = 0$ for all except laryngospasm simulation

$F_C = a_{FS}$ for laryngospasm

6. Forehead-Wrinkling Signal (F_h)

$F_h = 0.33\ a_{FS}$ for $0 < A \leq 1.1$ and $D_{es} < 22$ mg

$F_h = (0.55 - 0.205A)\ a_{FS}$ for $1.1 < A \leq 2.6$ and $D_{es} < 22$ mg

$F_h = 0$ for $A > 2.6$ or $D_{es} > 22$ mg

$F_h = a_{FS}$ for sensitive reaction to airway insertion or bucking (see Section C, below)

C. SENSITIVITY OF LARYNX TO STIMULATION BY AIRWAY AND LARYNGOSCOPE

For $A \leq 1.65$ and $D_{es} < 5.5$ mg, the manikin is sensitive to airway insertion - i.e., laryngospasm, bucking, and brow wrinkling are keyed upon airway insertion, and the eyelid is made 100% tense.

For $A > 1.65$ or $D_{es} > 5.5$ mg, no stimulation by airway insertion.

For $A < 1.1$ and $D_{es} < 5.5$ mg, bucking starts if the tube is in place in the manikin.

Bucking ceases with the tube in place when $A > 1.1$ or $D_{es} > 11$ mg.

D. COLOR SIGNAL (C_c) AS A FUNCTION OF OXYGEN LEVEL

$C_c = 0$ for $O_2T \geq 15$ volts (i.e., 6 vol%)

$C_c = (0.045\ a_{FS})(15 - O_2T)$ for $O_2T < 15$ volts

E. FASCICULATIONS AS A FUNCTION OF SUCCINYLCHOLINE

$M_f = 0$ for all $D_{es} < 5.5$ mg or $F_f = 1$, where M_f is the muscle-fasciculation signal and F_f is the fasciculation-flag signal, which is set to unity after the first fasciculation of the patient.

$M_f = 1$ with duration of 10 sec for $30 \leq D_s \leq 40$ mg and $F_f = 0$, where D_s gives the amount of succinylcholine injected (mg).

$M_f = 1$ with duration of 15 sec for $D_s > 40$ mg and $F_f = 0$

$F_f = 1$ after M_f has gone to 1

$F_f = 0$ on reset.

APPENDIX IV

PROGRAM LISTING

Succeeding pages present a list in DDP-24 DAP language that represents the program used by the digital portion of the hybrid analog/digital computer to control, monitor, and calculate various parameters in the operation of the anesthesiological training simulator.

```
00883 CARDS READ.
*
*   =      =                  MAST-MONITOR FOR ANEST. TRAINER
    = REL =
MAST= ITC =0                  =DISABLE INTERRUPT
    = CRA =
    = STA ='663               =RESET RUN COUNT
    = OCP ='1012              =ENABLE OUTPUT CHANNEL
    = OCP ='1013              =ENABLE DECODER
    =CALL =CRES               =CLEAR RESP
    = CALL=CDLA               =CLEAR DELAY ROUTINE
    = CALL=CNED               =CLEAR NEEDLE ROUTINE
    = CALL=CCIR               =CLEAR CIRCULATION ROUTINE
    = CALL=CDRU               =CLEAR DRUG ROUTINE
    = CALL=CACT               =CLEAR ACTUATIONS
    = CRA =
    = STA ='760               =RESET TIME
    = CRA =
    = STA ='762
    = STA ='763
    = STX ='761               =SET IC FLAG
    = CRA =
    = TAB =                   =CLEAR B
    = LDA =CLOK               =CLOCK INTERVAL IN MILLISECONDS
    = DIV =THOU               =FORM CLOCK INTERVAL IN SECONDS
    = STB ='736
    = LDB =CLOK
    = MPY =THOU
    = DIV =SEVN
    = STB =TEMP
    = LDA =IREG
    = SUB =TEMP
    = ADD =RUNT
    = STD =M1                 =SET UP TIME INT. FOR FALSE INTERR.
    = LDA =INTJ
    = STA =1                  =LOAD INTERRUPT JUMP CELL
    = SKS ='10                =IS SENSE SWITCH 4 SET
    = JMP =INT                =YES
    = ITC ='40000             =ENABLE INTERRUPT
    = OCP ='5041              =STOP CLOCK
    = OCP ='5040              =START CLOCK
    = JMP =*                  =WAIT FOR INTERRUPT
 INT = NOP =
    = OCP ='5041              =STOP CLOCK
    = OCP ='5040              =START CLOCK
= LDA =INPA
= LDB =ICNA
= CALL=ANIO              =INPUT PARAMETERS
= MZE ='13               =MUX. CHANG. 0-12
= LDA =INP
= STA ='751              =STORE NEEDLE VOLTAGE
= LDA =INP&1
= STA ='752              =STORE DRUG DOSE
= LDA =INP&2
= STA ='767              =STORE SPHYGMOMANOMETER PRESSURE
= LDA =INP&3
= STA ='757              =STORE O2V FLOW
= LDA =INP&4
= STA ='754              =STORE O2  FLOW
= LDA =INP&5
= STA ='756              =STORE N2O FLOW
= LDA =INP&6
= STA ='755              =STORE CYCLO FLOW
= LDA =INP&7
= STA ='770              =STORE VERNITROL FLOW
= LDA =INP&8
= LDB =RLGA
= CALL=FUBR
= STA ='771              =STORE RIGHT LUNG POSITION
= LDA =INP&9
= LDB =LLGA
= CALL=FUBR
= STA ='772              =STORE LEFT LUNG POSITION
= LDA =INP&10
= LDB =SLGA
= CALL=FUBR
= STA ='773              =STORE  SMALL RIGHT LUNG POS.
= LDA =INP&11
= STA ='774              =STORE AIRWAY POSITION
= LDA ='754
= LDB =TO2
= CALL=FUBR
= STA ='754              =LINEARIZE O2 INPUT
= LDA ='757
= LDB =TO2V
= CALL=FUBR
= STA ='757              =LINEARIZE O2V INPUT
= LDA ='756
= LDB =TN2O
= CALL=FUBR
```

```
     = STA ='756              =LINEARIZE N2O INPUT
     = LDA ='755
     = LDB =TCYC
     = CALL=FUBR
     = STA ='755              =LINEARIZE CYCLO INPUT
     = LDA ='770
     = LDB =TVER
     = CALL=FUBR
     = STA ='770              =LINEARIZE VERNITROL INPUT
     = LDA ='754              =GET O2 INPUT
     = ADD ='757              =ADD O2V INPUT
     = ADD ='770              =ADD VERNITROL INPUT
     = STA ='754              =STORE TOTAL O2 FOR OUTPUT
     = OCP ='1014
     = OCP ='1012
     = OCP =1
     = INM ='766              =INPUT CONSOLE STATUS WORD
MT   = NOP =                  =START  MODE SWITCH TEST
     = SKS*=IC
     = NOP =
     = SKS*=IC                =IC ON
     = JMP =MT1               =YES
     = SKS*=HOLD              =NO
     = NOP =
     = SKS*=HOLD              =HOLD ON
     = JMP =MT2               =YES
     = SKS*=OP                =NO
     = NOP =
     = SKS*=OP                =OPERATE ON
     = JMP =MT3               =YES
     = LDA ='762              =PICK UP HOLD FLAG
     = JZE =*&2               =IS HOLD FLAG SET,NO
     = JMP =MTHD              =YES,GO TO HOLD
     = LDA ='763
     = JZE =*&2               =IS OPERATE FLAG SET,NO
     = JMP =MT4               =YES,GO RESET PRINT
     = STX ='761              =SET IC FLAG
     = JMP =MTIC              =GO TO IC
MT1  = CRA =
     = STA ='762              =CLEAR HOLD FLAG
     = STA ='763              =CLEAR OPERATE FLAG
     = STX ='761              =SET IC FLAG
     = SKS*=HOLD
     = NOP =
     = SKS*=HOLD              =IS HOLD ON
```

```
      = HLT =1                    =YES,ERROR HALT
      = SKS*=OP                   =NO
      = NOP =
      = SKS*=OP                   =IS OPERATE ON
      = HLT =2                    =YES,ERROR HALT
      = JMP =MTIC                 =NO,GO TO IC
  MT2 = CRA =
      = STA ='761
      = STA ='763
      = STX ='762                 =SET HOLD FLAG
      = SKS*=OP
      = NOP =
      = SKS*=OP                   =IS OPERATE ON
      = HLT =3                    =YES,ERROR HALT
      = JMP =MTHD                 =NO,GO TO HOLD
  MT3 = LDA ='761                 =GET IC FLAG
      = JZE =*&3                  =IS IT SET,NO
  MT4 = LDA =PRIA                 =YES,GET INITIAL PRINT STORAGE ADDR.
      = STA ='667
      = CRA =
      = STA ='761                 =RESET IC FLAG
      = STA ='762                 =RESET HOLD FLAG
      = STX ='763                 =SET OP FLAG
      = JMP =MTOP                 =GO TO OPERATE
  MTIC= NOP =                     =START IC MODE
      = CALL=PRIN                 =GO TO PRINT
      = OCP =2
      = OTM =ICMC                 =PUT ANALOG IN IC
      = CALL=CRES
      = CALL=CDLA
      = CALL=CNEC
      = CALL=CCIR
      = CALL=CDRU
      = CALL=CACT                 =CLEAR ACTUATIONS
      = CRA =
      = STA ='760                 =RESET TIME
  MTI1= CALL=RESP                 =CALCULATE LUNG POSITION IN RESP
      = CALL=ACTS                 =GO TO BLINK ROUTINE
      = JMP =MO
  MTHD= NOP =                     =START HOLD MODE
      = CALL=PRIN                 =GO TO PRINT
      = OCP =2
      = OTM =HDMC                 =PUT ANALOG IN HOLD
      = CALL=NEDL
      = JMP =MTI1                 =GO TO CALCULATE LUNG POSITION
```

```
MTOP= NOP =                       =START OPERATE MODE
    = OCP =2
    = OTM =OPMD                   =PUT ANALOG IN OP
    = CALL=NEDL
    = CALL=DRUG                   =DO DRUG ROUTINE
    = CALL=CIRC                   =DO CIRCULATION ROUTINE
    =CALL =RESP                   =DO RESPIRATION ROUTINE
    = CALL=ACTS                   =ACTUATION ROUTINE
    = LDA ='760
    = ADD =ONE
    = STA ='760                   =STEP TIME
MO  = NOP =                       =START OUTPUT
    = CRA =                       =START EFF. DRUG SELECTION
    = LDB ='766                   =PICK UP CONSOLE WORD
    = LLR =4                      =SHIFT IN DRUG SELECTION
    = SKG =TEN                    =IS DRUG NUMBER GREATER THAN 10
    = JMP =*&2                    =NO
    = HLT ='12                    =YES,ERROR HALT
    = STA =DRSL
    = JZE =MOA
    = ADD =DEAD
    = STD =MOB                    =SET UP EFF. DRUG ADDRESS
    = LDA =DRSL
    = ADD =DOCN
    = STD =*&1
    = LDA =**                     =PICK UP DRUG SCALING CONSTANT
    = STA =OCN
    = JMP =MOB
    = NOP =
MOA = LDA =DCN&9                  =PICK UP SCALING CONST. FOR NO DRUG
    = JMP =*-4
MOB = LDA =**                     =EFF. DRUG
    = STA =OUT
    = LDA ='742                   =SYSTOLIC PRESSURE -PS
    = STA =OUT&1
    = LDA ='743                   =DIASTOLIC PRESSURE -PD
    = STA =OUT&2
    = LDA ='747                   =EFF. 02
    = STA =OUT&3
    = LDA ='753                   =ANESTHESIA LEVEL
    = STA =OUT&4
    = LDA ='733                   =VENTILATION RATE -VR
    = STA =OUT&5
    = LDA ='741                   =PULSE RATE -PR
    = STA =OUT&6
```

```
      = LDA ='672                =JAW TENSION
      = LDB =JAWA
      = CALL=FUBR
      = STA =OUT&7
      = LDA ='673                =EYELID TENSION
      = LDB =EYEA
      = CALL=FUBR
      = STA =OUT&8
      = LDA ='674                =PUPIL DILATION
      = LDB =PUPA
      = CALL=FUBR
      = STA =OUT&9
      = LDA ='675                =SKIN COLOR
      = LDB =CLRA
      = CALL=FUBR
      = STA =OUT&10
      = LDA ='744                =LUNG POSITION
      = LDB =LNGA
      = CALL=FUBR
      = STA =OUT&11
      = LDA ='676                =FOREHEAD WRINKLE
      = LDB =FHDA
      = CALL=FUBR
      = STA =OUT&12
      = LDA ='677                =VOCAL CORD TENSION
      = LDB =VOCA
      = CALL=FUBR
      = STA =OUT&13
      = LDA ='754                =TOTAL O2
      = STA =OUT&14
      = LDA ='756                =N2O
      = STA =OUT&15
      = LDA ='755                =CYCLO
      = STA =OUT&16
      = LDA ='770                =VERNITROL
      = STA =OUT&17
      = LDA =OUTA
      = LDB =OCNA
      = CALL=ANIO                =OUTPUT VARIABLES
      = PZE ='0021               =DAC CHAN. 1-18
      = SKS ='10                 =IS SENSE SWITCH 4 SET
      = JMP =*&2                 =YES
      = JMP =M2                  =NO
      = ITC =0                   =DISABLE INTERRUPT
M1    = LDX =**,1
```

```
    = JXI =*,1            =IS TIME INTERVAL OVER
    = JMP =INT            =YES
M2  = SKS =1              =IS SENSE SWITCH 1 SET
    = JMP =M3             =YES
    = JRT =0              =NO,CONTINUE
M3  = OCP ='5041          =STOP CLOCK
    = JRT =*&1            =JUMP TO DEBUG
    = PZE ='20
CLOK= DEC =100
IC  = OCT =60001
HOLD= OCT =60002
OP  = OCT =60003
ICN = DEC =0,20B11,300B11,14B11,14B11,14B11,14B11,14B11,10B8
    = DEC =10B8,10B8,20B11,0,0,0,0,0,0,0,0
ICNA= PZE =ICN
INP = BSS =20
INPA= PZE =INP
INTJ= JMP =INT
IREG= OCT =77777
DRSL= OCT =0
DEAD= OCT =711
DOCN= PZE =DOCN
DCN = DEC =.001B0,.01B0,.01B0,.1B0,1,1,1,1,1,1
OCN = DEC =.001B0,.005B0,.005B0,0,.2B0,.0125B0,.005B0
    = DEC =.01B0,.01B0,.05B0,.01B0,.4B3,.01B0,.01B0
    = DEC =.1667B0,.0833B0,.9999B0,.9999B0,0,0
OCNA= PZE =OCN
ONE = OCT =1
SEVN= DEC =7
TEN = DEC =10
THOU= DEC =1000
OUT = BSS =20
OUTA= PZE =OUT
PRIA= OCT =405
RSET= PZE =MAST
RUNT= DEC =4500
TEMP= OCT =0
ICMD= OCT =1000
HDMD= OCT =1100
OPMD= OCT =1200
TO2 = PZE =O2L
O2L = DEC =15
    = DEC =00.88B11,00.00B11,00.93B11,00.25B11,00.99B11,00.50B11
    = DEC =01.06B11,00.75B11,01.35B11,01.12B11,01.72B11,01.60B11
    = DEC =02.24B11,02.00B11,03.40B11,02.80B11,03.90B11,03.00B11
```

```
      = DEC =05.00B11,03.48B11,06.50B11,04.02B11,08.00B11,04.50B11
      = DEC =10.00B11,05.04B11,12.00B11,05.55B11,14.00B11,06.00B11
 TO2V= PZE =O2VL
 O2VL= DEC =15
      = DEC =00.70B11,.000B11,00.80B11,.040B11,01.00B11,.075B11
      = DEC =01.25B11,.115B11,01.50B11,.150B11,02.00B11,.200B11
      = DEC =02.50B11,.247B11,03.00B11,.284B11,04.00B11,.354B11
      = DEC =05.00B11,.411B11,06.50B11,.486B11,08.00B11,.550B11
      = DEC =10.00B11,.623B11,12.00B11,.685B11,14.00B11,.733B11
 TN2O= PZE =N2OL
 N2OL= DEC =15
      = DEC =00.80B11,00.00B11,00.83B11,00.50B11,00.91B11,01.00B11
      = DEC =01.30B11,02.60B11,01.65B11,03.40B11,02.10B11,04.20B11
      = DEC =02.80B11,05.10B11,03.60B11,06.00B11,04.50B11,06.90B11
      = DEC =05.50B11,07.75B11,07.00B11,08.75B11,08.50B11,09.60B11
      = DEC =11.00B11,10.85B11,12.50B11,11.50B11,14.00B11,12.10B11
 TCYC= PZE =CYCL
 CYCL= DEC =15
      = DEC =01.00B11,.000B11,01.02B11,.050B11,01.04B11,.100B11
      = DEC =01.20B11,.150B11,01.50B11,.200B11,02.00B11,.260B11
      = DEC =02.50B11,.310B11,03.00B11,.350B11,04.00B11,.423B11
      = DEC =05.50B11,.510B11,07.50B11,.603B11,09.50B11,.680B11
      = DEC =11.00B11,.728B11,12.50B11,.770B11,14.00B11,.800B11
 TVER= PZE =VERL
 VERL= DEC =15
      = DEC =00.00B11,.000B11,01.00B11,.000B11,02.00B11,.000B11
      = DEC =03.00B11,.000B11,04.00B11,.000B11,05.00B11,.000B11
      = DEC =06.00B11,.000B11,07.00B11,.000B11,08.00B11,.000B11
      = DEC =09.00B11,.000B11,10.00B11,.000B11,11.00B11,.000B11
      = DEC =12.00B11,.000B11,13.00B11,.000B11,14.00B11,.000B11
 RLGA= PZE =RLGT
 RLGT= DEC =5
      = DEC =0.0B8,0.0B8,2.5B8,2.5B8,5.0B8,5.0B8,7.5B8,7.5B8,10B8,10B8
 LLGA= PZE =LLGT
 LLGT= DEC =5
      = DEC =0.0B8,0.0B8,2.5B8,2.5B8,5.0B8,5.0B8,7.5B8,7.5B8,10B8,10B8
 SLGA= PZE =SLGT
 SLGT= DEC =5
      = DEC =0.0B8,0.0B8,2.5B8,2.5B8,5.0B8,5.0B8,7.5B8,7.5B8,10B8,10B8
 JAWA= PZE =JAWT
 JAWT= DEC =5
      = DEC =0B11,0B11,25B11,25B11,50B11,50B11,75B11,75B11,100B11,100B11
 EYEA= PZE =EYET
 EYET= DEC =5
      = DEC =0B11,0B11,25B11,25B11,50B11,50B11,75B11,75B11,100B11,100B11
```

```
PUPA= PZE =PUPT
PUPT= DEC =5
    = DEC =0B11,0B11,25B11,25B11,50B11,50B11,75B11,75B11,100B11,100B11
CLRA= PZE =CLRT
CLRT= DEC =5
    = DEC =0B11,0B11,25B11,25B11,50B11,50B11,75B11,75B11,100B11,100B11
LNGA= PZE =LNGT
LNGT= PZE =6
    = DEC =0B3,0B3,1B3,1B3,2B3,2B3,3B3,3B3,4B3,4B3,5B3,5B3
FHDA= PZE =FHDT
FHDT= DEC =5
    = DEC =0B11,0B11,25B11,25B11,50B11,50B11,75B11,75B11,100B11,100B11
VOCA= PZE =VOCT
VOCT= DEC =5
    = DEC =0B11,0B11,25B11,25B11,50B11,50B11,75B11,75B11,100B11,100B11
    = NOP =
    = END =MAST
```

```
00376 CARDS REAC.
*
*    =       =                       NEDL-INJECTABLE DRUG SUBROUTINE
CNED= NTRY=NO
NEDL= NTRY=N1
    = REL =
NO  = JMP =**
    = LDX =-10,1
    = CRA =
    = STA =CUDO&10,1                 =CLEAR CUM. DOSE CELLS
    = STA ='700&10,1                 =CLEAR CUM. INJECTABLE DRUGS
    = JXI =*-2,1
    = CRA =
    = STA =VFLG                      =CLEAR VALID LEVEL FLAG
    = STA =VLLV                      =CLEAR VALID LEVEL
    = OCP ='1042                     =OPEN VALVE
    = OCP ='1041                     =RESET OC
    = JMP*=NO                        =EXIT
 N1 = JMP =**
    = STX =N8,1                      =STORE INDEX
    = LDA ='751
    = STA =VN                        =STORE NEEDLE VOLTAGE
    = LDA ='752
    = STA =IDOS                      =STORE INPUT DOSE
    = LDA =VN                        =PICK UP NEEDLE VOLTAGE
    = SKG =VO                        =IS NEEDLE INSERTED
    = JMP =*&2                       =NO
    = JMP =N2                        =YES
    = OCP ='1042                     =OPEN VALVE
    = OCP ='1041                     =RESET OC
    = LDA =VFLG
    = JZE =N1A                       =IS VALID FLAG SET,NO
    = LDA =DRGP                      =YES,GET PRINT DRUG NO.
    = TAX =,1                        =INSERT IN INDEX
    = LDB =VLLV                      =GET INJECTED AMOUNT
    = MPY =MGCC,1                    =CONVERT TO MG
    = LRS =12
    = LDA =DPCD,1                    =GET DRUG PRINT CODE
    = ORA ='760                      =INSERT TIME
    = CALL=PSTR                      =STORE PRINT ENTRY
 N1A = CRA =
    = STA =VFLG                      =RESET VALID FLAG
    = STA =VLLV                      =RESET VALID LEVEL
    = JMP =N7
 N2  = NOP =
     = LDX =-9,1
N3   = LDA =NVLT&9,1
     = SKG =VN                =IS NEEDLE BOUNDARY GREATER THAN VOLTAGE
     = JMP =*&2               =NO
     = JMP =N4                =YES
     = JXI =N3,1
N4   = ADX =9,1               =CALCULATE DRUG NUMBER
     = STX =DRUG,1
     = LDA =DRUG
     = SKN =DRGO              =IS DRUG SAME AS BEFORE
     = JMP =*&4               =YES
     = OCP ='1042             =NO,TURN OFF LIGHT
     = OCP ='1041
     = STA =DRGO              =UPDATE DRUG NUMBER
     = ADD =OCLT              =FORM DRUG OCP NUMBER
     = STD =*&1
     = OCP =**                =TURN ON INJECTED DRUG LIGHT
N5   = LDA =VFLG
     = JZE =*&2               =IS VALID FLAG SET,NO
     = JMP =N6                =YES
     = CRA =
     = STA =VLLV              =MAKE VALID LEVEL ZERO
     = IRX =VFLG              =SET VALID FLAG
N6   = LDA =IDOS
     = SKG =VLLV              =IS INPUT DOSE GREATER THAN VALID LEVEL
     = JMP =N7                =NO
     = SUB =VLLV              =YES,FORM DELTA DOSE
     = STA =DLTD              =STORE DELTA DOSE
     = SKG =DPTH              =IS DELTA DOSE GREATER THAN THRESH.
     = JMP =*&4               =NO
     = LDA =DRUG              =YES
     = STA =DRGP              =UPDATE DRUG NO.
     = LDA =DLTD              =PICK UP DELTA DOSE
     = ADD =CUDO,1            =UPDATE CUMULATIVE DOSE
     = STA =CUDC,1
     = LDA =IDOS
     = STA =VLLV              =UPDATE VALID LEVEL
     = LDA =DRUG
     = SKN =SUCC              =IS DRUG SUCCINYL.
     = JMP =*&2               =YES
     = JMP =*&3               =NO
     = LDA =VLLV
     = STA ='776              =STORE  INJECTED SUCC. IN XCEL
N7   = NOP =
     = LDA ='762              =PICK UP HOLD FLAG
```

```
      = JZE =*&2                     =IS HOLD MODE ON,NO
      = JMP =N8                      =YES
      = CRA =
      = LDB ='760                    =PICK UP TIME
      = DIV =TEN
      = JZE =*&2                     =TIME TO STORE IN DELAY LINE,YES
      = JMP =N8                      =NO
      = LDX =-4,1
      = LDB =CUDO&4,1
      = MPY =MGCC&4,1
      = LLS =11                      =PUT BINARY POINT AT 11
      = CALL=DLAY                    =STORE CUM. DOSES IN DELAY LINES
      = STA ='700&4,1
      = JXI =*-5,1
N8    = LDX =**,1                    =RESTORE INDEX
      = JMP*=N1                      =EXIT
CUDO= OCT =0,0,0,0,0,0,0,0,0,0
DLTD= OCT =0
DPCD= OCT =04000000,05000000,07000000,06000000
DPTH= OCT =100
DRGP= OCT =0
DRUG= OCT =0
DRGO= OCT =0
SUCC= OCT =1
CCLT= OCT =1030
IDOS= OCT =0
NVLT= OCT =10000000,24000000,32000000,37777777,0
    = OCT =0,0,0,0,0
TEN = DEC =10
VFLG= OCT =0
VLLV= OCT =0
VN  = OCT =0
VO  = OCT =03000000
MGCC= DEC =25B11,20B11,10B11,10B11,10B11
    = DEC =10B11,10B11,10B11,10B11,10B11
    = NOP =
    = END =NO
```

```
00126 CARDS READ.
*
*   =     =                           DRUG SUBROUTINE
*   =     =                             CALCULATES EFFECTIVE DRUG
*   =     =                             CONCENTRATIONS FROM CUMULATIVE
*   =     =                             INJECTABLE DRUG DOSES.ALSO
*   =     =                             CALCULATES ANESTHESIA LEVEL
CDRU= NTRY=DR0
DRUG= NTRY=DR2
    = REL =
DR0 = JMP =**
    = STX =DR1,1                      =STORE INDEX
    = LDX =-10,1
    = CRA =
    = STA ='712&10,1                  =CLEAR EFFECTIVE DRUG STORAGE
    = JXI =*-1,1
    = LDX =-20,1
    = CRA =
    = STA =DS0&20,1                   =CLEAR LEAD AND LAG STORAGE
    = JXI =*-1,1
    = CRA =
    = STA ='753                       =CLEAR A LEVEL
    = LDX =-20,1
    = CRA =
    = LDB ='736                       =PICK UP CLOCK INT.
    = DIV =TMC&20,1                   =DIVIDE BY TIME CONSTANT
    = STB =KC0&20,1                   =STORE TRANSFER FUNCTION MULTIPLIER
    = JXI =*-4,1
DR1 = LDX =**,1                       =RESTORE INDEX
    = JMP*=DR0                        =EXIT
DR2 = JMP =**
    = STX =DR8,1                      =STORE INDEX
    = LDA =DS0A
    = STD =DS0B
    = LDA =DG0A
    = STD =DG0B                       =INITIALIZE STORAGE ADDRESSES
    = LDX =-10,1
DR3 = LDA =KD0&10,1                   =PICK UP LEAD TIME CONST.
    = STA =DR5
    = LDB ='700&10,1                  =PICK UP CUM. INPUT DOSE
    = MPY =KT0&10,1
DR4 = LDB =DS0B                       =PICK UP LEAD STORAGE ADDR.
    = CALL=LEAD
DR5 = PZE =**                         =TIME CONST FOR LEAD
    = STA =TLED                       =STORE LEAD OUTPUT
    = LDB ='740                  =PICK UP CIRCULATION
    = MPY =KCO&10,1              =CALC. LAG TIME CONST.
    = LLS =11
    = STA =DR7                   =SET UP LAG TIME CONST.
DR6 = LDB =DGOB                  =PICK UP LAG STORAGE ADDR.
    = LDA =TLED                  =PICK UP LEAD OUTPUT
    = CALL=LAG
DR7 = PZE =**
    = STA ='712&10,1             =STORE IN EFFECTIVE DRUG CELL
    = SKG =SOFT&10,1             =IS EFF. LEVEL GREATER THAN SOFT LIMIT
    = JMP =*&3                   =NO
    = LDA =SLTC&10,1             =YES
    = STA =KCO&10,1              =REPLACE LAG T. C. BY SOFT LIMIT T. C.
    = IRX =DSOB
    = IRX =DGOB                  =STEP STORAGE ADDRESSES
    = JXI =DR3,1                 =THRU ALL DRUGS,NO
    = NOP =                      =YES,START A LEVEL CALC
    = LDB ='712                  =PICK UP EFF. PENTOTHAL
    = MPY =KP1
    = STA =A
    = LDB ='725                  =PICK UP EFF. CYCLC
    = MPY =KCY3
    = ADD =A
    = STA =A
    = LDB ='726                  =PICK UP EFF N2O
    = MPY =KN1
    = ADD =A
    = STA ='753                  =STORE A LEVEL
DR8 = LDX =**,1                  =RESTORE INDEX
    = JMP*=DR2                   =EXIT
DSOA= PZE =DSO
DGOA= PZE =DGO
DSOB= OCT =0
DGOB= OCT =0
DSO = OCT =0,0,0,0,0,0,0,0,0,0
DGO = OCT =0,0,0,0,0,0,0,0,0,0
TLED= OCT =0
A   = OCT =0
KP1 = DEC =.00918O
KN1 = DEC =.0005B0
KCY3= DEC =.0149B0
KCO = OCT =0,0,0,0,0,0,0,0,0,0
KDO = OCT =0,0,0,0,0,0,0,0,0,0
KTO = DEC =.668B0,.668B0,.668B0,.668B0,.668B0
    = DEC =.668B0,.668B0,.668B0,.668B0,.668B0
TMC = DEC =65,65,390,97,65,65,65,65,65,65
    = DEC =225,225,18000,18000,225,225,225,225,225,225
SOFT= DEC =2047B11,2047B11,22B11,2047B11,2047B11
    = DEC =2047B11,2047B11,2047B11,2047B11,2047B11
SLTC= DEC =.001538B0,.001538B0,.0000125B0,.001B0,.001538B0
    = DEC =.001538B0,.001538B0,.001538B0,.001538B0,.001538B0
    = NOP =
    = END =DR0
```

```
00097 CARDS READ.
*
*   =     =                      CIRC-CIRCULATION  SUBROUTINE
*   =     =                          -CALCULATES CIRCULATION RATE,
*   =     =                          -PULSE RATE,SYSTOLIC AND
*   =     =                          -DIASTOLIC PRESSURES
CCIR= NTRY=CR0
CIRC= NTRY=CR1
    = REL =
CR0 = JMP =**
    = LDA =CNOM
    = STA ='740
    = LDA =PRNM
    = STA ='741
    = LDA =PSNM
    = STA ='742
    = LDA =PDNM
    = STA ='743                  =INITIALIZE C,PR,PS,AND,PD TO NOMINAL
    = OCP =2
    = OTM =DE21                  =RESET BELOW SYSTOLIC
    = OTM =DE23                  =RESET HEART ARREST
    = CRA =
    = STA ='665                  =CLEAR HEART ARREST FLAG
    = STA ='666                  =CLEAR FIBRILLATION FLAG
    = STA ='745                  =CLEAR DIASTOLIC PRESSURE DELTA
    = STA ='746                  =CLEAR PULSE RATE DELTA
    = STA ='670                  =CLEAR SYSTOLIC PRESSURE DELTA
    = JMP*=CR0                   =EXIT
CR1 = JMP =**
    = STX =CR6,1                 =STORE INDEX
    = LDX =-3,1
    = LDA ='753                  =PICK UP ANEST. LEVEL
    = SUB =ONFV                  =SUBTRACT 1.5
    = JPL =*&2                   =IS RESULT NEGATIVE,NO
    = CRA =                      =YES,SET RESULT =0
    = STA =T0
CR3 = LDB =T0                    =START F1D,F2D,F3D CALCULATIONS
    = MPY =A2&3,1
    = LLS =11
    = STA =T1
    = LDB ='753                  =PICK UP A LEVEL
    = MPY =A1&3,1
    = LLS =11
    = ADD =T1
    = STA =T1
= LDB ='714             =PICK UP VE1
= MPY =KVE1&3,1
= LLS =11
= STA =T2
= LDB ='715             =PICK UP VE2
= MPY =KVE2&3,1
= LLS =11
= ADD =T2
= SUB =T1
= STA =F1D&3,1
= JXI =CR3,1            =END F1D,F2D,F3D CALCULATIONS
= LDA ='714             =LOAD VE1
= ADD ='715             =ADD VE2
= STA ='737             =STORE TOTAL VASOPRESSORS
= LDA ='747             =LOAD O2
= LDB =F3O
= CALL=FUBR
= STA =F3OF             =STORE F3O2 FUNCTICN
= STA ='764             =STORE F3O2 FOR RESP
= LDA ='750             =LOAD CO2
= LDB =F3C
= CALL=FUBR
= STA =F3CF             =STORE F3CO2 FUNCTION
= STA ='765             =STORE F3CO2 FOR RESP
= LDA =F3OF             =START PR CALCULATION
= SUB =ONE
= TAB =
= MPY =NUM6
= LLS =11
= ADD =ONE
= STA =F3PO             =STORE F3'(O2)
= LDB =F3CF
= MPY =NUM2
= LLS =11
= ADD =PRNM
= TAB =
= MPY =F3PO             =MULTIPLY BY F3'(O2)
= LLS =11
= ADD =F3D
= ADD ='746
= SKG =PRMX             =HAS PR REACHED LIMIT
= JMP =*&2              =NO
= LDA =PRMX             =YES
= JPL =*&2              =RESULT POSITIVE,YES
= CRA =
      = STA ='741                     =END PR CALCULATION
      = LDB =F3CF                     =START PD CALCULATION
      = MPY =NUM7
      = LLS =11
      = ADD =PSNM
      = TAB =
      = MPY =F30F
      =LLS  =11
      = STA =T6
CR4A= LDA ='745                      =PICK UP MANUAL PRESSURE
      = ADD =F2D
      = ADD =T6
      = SUB =NUM3
      = SKG =PDMX                     =HAS PD REACHED LIMIT
      = JMP =*&2                      =NO
      = LDA =PDMX                     =YES
      = JPL =*&2                      =RESULT POSITIVE,YES
      = CRA =
      = STA ='743                     =STORE PD- DIASTOLIC PRESSURE
      = LDB =F3CF                     =START PS CALCULATION
      = MPY =NUM8
      = LLS =11
      = ADD =PSNM
      = TAB =
      = MPY =F30F
      = LLS =11
      = STA =T6
      = LDA ='670                     =PICK UP PS SWITCH AND DELTA CHANGE
      = ADD =F1D
      = ADD =T6
      = SKG =PSMX                     =HAS PS REACHED LIMIT
      = JMP =*&2                      =NO
      = LDA =PSMX                     =YES
      = JPL =*&2                      =RESULT POSITIVE,YES
      = CRA =
      = STA ='742                     =STORE PS- SYSTOLIC PRESSURE
      = SKG ='767                     =IS PS GREATER THAN SPHYG. PRESSURE
      = JMP =*&3                      =NO
      = OCP ='1024                    =YES,TURN ON BELOW SYST. LIGHT
      = JMP =*&4
      = NOP =
      = OCP =2
      = OTM =DE21                     =TURN OFF LIGHT
      = LDB ='742                     =START C  CALC.,LOAD PS
      = MPY ='741                     =MULTIPLY BY PR
```

```
    = LLS =5                    =SHIFT TO B17
    = TAB =
    = MPY =NUM4                 =MULTIPLY BY KC
    = LLS =6                    =SHIFT RESULT TO B11
    = SKG =CMAX                 =IS RESULT GREAT THAN MAX. C
    = JMP =CR5                  =NO
    = LDA =CMAX                 =YES,PICK UP MAX. C
CR5 = STA ='740                 =STORE C
    = LDA ='766                 =PICK UP CSW
    = ANA =HAMK                 =STRIP OUT HEART ARREST BIT
    = STA ='665                 =STORE BIT AS HEART ARREST FLAG
    = JZE =CR5C                 =IS BIT ZERO,YES
CR5A= OCP ='1023                =NO,TURN ON OC
    = CRA =
    = STA ='740                 =MAKE  CIRC. ZERO
    = JMP =CR6
CR5B= OCP =2
    = OTM =DE23                 =RESET HEART ARREST OR FIBR. OC
    = JMP =CR6
CR5C= LDA ='766                 =GET CONSOLE WORD
    = ANA =FIMK                 =STRIP OUT FIBRILL. BIT
    = STA ='666                 =STORE BIT AS FIBR. FLAG
    = JZE =CR5B                 =IS IT ZERO,YES
    = JMP =CR5A                 =NO
CR6 = LDX =**,1                 =RESTORE INDEX
    = JMP*=CR1                  =EXIT
A1  = DEC =6.25B11,3B11,0
A2  = DEC =26B11,22.5B11,10.96B11
CNOM= DEC =6.5B11
KVE1= DEC =3B11,1B11,1.48B11
KVE2= DEC =12.78B11,6.42B11,-2.76B11
ONE = DEC =1B11
ONFV= DEC =1.5B11
PRNM= DEC =70B11
PSNM= DEC =120B11
PDNM= DEC =80B11
PRMX= DEC =200B11
PSMX= DEC =240B11
PDMX= DEC =200B11
KA1 = DEC =20B11
KA2 = DEC =12B11
KA3 = DEC =4B11
KA1A= OCT =0
KA2A= OCT =0
KA3A= OCT =0
```

```
TO   = OCT =0
T1   = OCT =0
T2   = OCT =0
T3   = OCT =0
T4   = OCT =0
T5   = OCT =0
T6   = OCT =0
F1D  = OCT =0
F2D  = OCT =0
F3D  = OCT =0
F3OF= OCT =0
F3CF= OCT =0
NUM1= DEC =20B11
NUM2= DEC =.286B11
NUM3= DEC =40B11
NUM4= DEC =.000773B0
NUM5= DEC =0
NUM6= DEC =2.14B11
NUM7= DEC =.0835B11
NUM8= DEC =.5B11
DE21= OCT =2500
DE23= OCT =2700
HAMK= OCT =4000
FIMK= OCT =2000
F3PO= OCT =0
CMAX= DEC =7.15B11
F3C  = PZE =F3CO
F3CO= DEC =15
     = DEC =40.0B11,00.00B11,42.5B11,00.70B11,45.0B11,02.00B11
     = DEC =47.5B11,04.00B11,50.0B11,06.00B11,52.5B11,09.00B11
     = DEC =55.0B11,12.70B11,60.0B11,22.00B11,65.0B11,31.00B11
     = DEC =70.0B11,40.00B11,77.5B11,54.00B11,80. B11,57.50B11
     = DEC =82.5B11,59.00B11,85.0B11,59.50B11,87.5B11,60.00B11
F30  = PZE =F302
F302= DEC =15
     = DEC =00.0B11,-0.50B11,02.5B11,&0.28B11,04.0B11,&0.95B11
     = DEC =05.0B11,&1.10B11,06.1B11,&1.15B11,07.5B11,&1.18B11
     = DEC =10.0B11,&2.00B11,15.0B11,&2.00B11,20.0B11,&1.18B11
     = DEC =25.0B11,&1.14B11,27.5B11,&1.12B11,32.5B11,&1.06B11
     = DEC =35.0B11,&1.03B11,37.5B11,&1.00B11,40.0B11,&1.00B11
     = NOP =
     = END =CRO
```

```
00221 CARDS READ.
*
*   =     =                       RESPIRATION SUBROUTINE
*   =     =                         CALCULATE BREATHING RATE,BREATHING
*   =     =                         AMPLITUDE, AND VENTILATION RATE
CRES= NTRY=R0
RESP= NTRY=R1
    = REL =
R0  = JMP =**                     =CLEAR RESP. ROUTINE
    = LDA =OSIC
    = STA =OSL1
    = STA =OSL2
    = LDA =COIC
    = STA =COSL                   =INITIALIZE TRANS. FUNC. STORAGE
    = LDA =O2IO
    = STA ='724                   =INITIALIZE OUTPUT O2
    = LDA =O2IF
    = STA ='747                   =INITIALIZE FUNTION O2
    = LDA =CO2F
    = STA ='750
    = STA ='735                   =INITIALIZE CO2 FUNCTION
    = STA =OVOL                   =INITIALIZE OLD VOLUME
    = CRA =
    = STA =CSL1
    = STA =CSL2
    = STA =NSL1
    = STA =NSL2                   =CLEAR TRANS. FUNC. STORAGE
    = STA =HYFL                   =CLEAR HYSTERESIS FLAG
    = STA ='725                   =CLEAR  DECY
    = STA ='726                   =CLEAR  DENO
    = STA =APFL                   =RESET AIRWAY PRINT FLAG
    = STA =BPFL                   =RESET BREATHING PRINT FLAG
    = LDX =-12,1
    = STA =TIMR&12,1              =CLEAR GAS FLOW PRINT PARAM.
    = JXI =*-1,1
    = LDA =BRIC
    = STA =BRLS
    = STA =BR
    = LDA =BAIC
    = STA =BALS
    = STA =BA
    = LDA =VRIC
    = STA =IVR                    =INITIALIZE BA,BR,AND INST. VR
    = STA =IVLS                   =INITIALIZE VENT. RATE LAG STORAGE
    = LDX =-12,1
```

```
     = CRA =
     = LDB ='736               =PICK UP CLOCK INT.
     = DIV =TC&12,1            =DIVIDE BY TIME CONSTANT
     = STB =CLG&12,1           =STORE TRANSFER FUNCTION MULTIPLIER
     = JXI =*-4,1
     = LDB =KSO
     = MPY ='736
     = STA =KS                 =CALCULATE SLOPE CONST.
     = JMP*=RO
R1   = JMP =**
     = STX =R15,1              =STORE INDEX
     = LDA ='763               =PICK UP OP FLAG
     = JZE =R14                =IS OPERATE MODE ON,NO
     = LDA ='754               =PICK UP TOTAL O2 INPUT
     = ADD ='755               =ADD CYCLO
     = ADD ='756               =ADD N2O
     = STA =GASS               =STORE SUM OF GASSES
     = LDB =IVRC               =START ALPHA CALC.
     = MPY =KN
     = STA =ALFA
     = LDB ='740               =PICK UP CIRCULATION
     = MPY =KN&1
     = ADD =ALFA
     = ADD =KN&2
     = STA =ALFA               =STORE ALPHA AT B11
     = LDA ='770
     = STA =CFLO&3             =STORE CURRENT VERNITROL FLOW
     = LDX =-3,1
R    = NOP =                   =START EFF. GAS CONC. CALC.
     = LDB =ZERO               =CLEAR B
     = LDA ='754&3,1
     = STA =CFLO&3,1           =STORE CURRENT FLOW
     = LRR =1                  =SHIFT TO PREVENT IMP. DIVIDE
     = DIV =GASS               =CALC. PER CENT OF GAS
     = LDA ='766               =PICK UP CONSOLE WORD
     = ANA =MKBT               =STRIP OUT MASK BIT
     = STA ='664               =STORE MASK FLAG
     = JZE =*&2                =IS MASK ON,NO
     = JMP =R4                 =YES
     = LDA ='766               =GET CONSOLE WORD
     = ANA =AWBT               =STRIP OUT AIRWAY BIT
     = JZE =R3A                =IS AIRWAY ATTACHED,NO
     = LDA =APFL               =YES
     = JZE =*&2                =IS PRINT FLAG ON,NO
     = JMP =R4                 =YES
     = LDA ='760              =GET TIME
     = ORA =ARCD              =INSERT AIRWAY ATTACHED CODE
     = CALL=PSTR              =STORE PRINT ENTRY
     = STX =APFL              =SET PRINT FLAG
     = JMP =R4
R3A  = LDA =APFL
     = JZE =R4A               =IS AIRWAY PRINT FLAG SET,NO
     = LDA ='760              =YES,GET TIME
     = ORA =ARCC&1            =INSERT AIRWAY REMOVED CODE
     = CALL=PSTR              =STORE PRINT ENTRY
     = CRA =
     = STA =APFL              =RESET PRINT FLAG
     = JMP =R4A
R4   = MPY =IVRC              =YES
     = JMP =R4C
R4A  = SKS =2                 =IS SENSE SWITCH 2 SET
     = JMP =R4B               =YES
     = LDB =PGAS&3,1          =NO,PICK UP NORMAL GAS PERCENT
     = JMP =R4
R4B  = LDB =PGAS&1            =CLEAR B
     = JMP =R4
R4C  = TAB =
     = MPY =KF&3,1            =MULTIPLY BY CONST.-BINARY POINT AT B23
     = LLS =13                =PUT BINARY POINT AT B10
     = STA =GASI
     = LDB =ALFA
     = MPY =CLG&3,1
     = LLS =11
     = STA =R5                =SET UP TIME CONST. FOR FIRST LAG
     = LDA =GASI
     = LDB =L1SA&3,1          =PICK UP LAG 1 STORAGE ADDR.
     = CALL=LAG               =DO FIRST LAG
R5   = PZE =**
     = STA =LG1S
     = LDA =TLG&3,1           =SET UP TIME CONST. FOR SECOND LAG
     = STA =R6
     = LDA =LG1S
     = LDB =L2SA&3,1          =PICK UP LAG 2 STORAGE ADDR.
     = CALL=LAG               =DO SECOND LAG
R6   = PZE =**
     = ARS =1                 =PUT BINARY POINT AT B11
     = STA ='724&3,1          =STORE IN EFFECTIVE GAS CELLS
     = JXI =R3,1
     = LDB =ALFA              =START CO2 CALCULATION
     = MPY =KC01              =CALCULATE TIME CONST. FOR CO2 LAG
```

```
    = LLS =11                       =PUT BINARY POINT AT B0
    = STA =R7                       =SET UP CO2 TIME CONST. FOR LAG
    = LDB =ZERO                     =CLEAR B
    = LDA =KCO2
    = DIV =ALFA                     =CALCULATE TCD AT B8
    = MPY =KCO3
    = LLS =11                       =CALCULATE CO2 LAG INPUT AT B8
    = LDB =LCOA
    = CALL=LAG
R7  = PZE =**
    = ARS =3                        =SHIFT BINARY POINT TO B11
    = STA =CO2
    = ADD ='671                     =ADD MANUAL SWITCH VALUE
    = JPL =*&2                      =IS CO2 POSITIVE,YES
    = CRA =                         =NO,MAKE CO2 ZERO
    = STA =CO2
    = STA ='734                     =STORE CO2 IN XCEL
    = LDB ='725
    = MPY =KCO4
    = STA =TCO
    = LDB ='712
    = MPY =KCO5
    = ADD =TCO
    = STA =TCO
    = LDA =CO2
    = SUB =TCO
    = JPL =*&2                      =IS CO2E POSITIVE,YES
    = CRA =                         =NO,MAKE CO2E ZERO
    = STA =CO2E                     =CALCULATE EFFECTIVE CO2 AT B11
    = LDB =CO2E
    = JST =SCAL
    = STA =EFFG                     =STORE SCALED EFF CO2 FOR FUNC
    = LDB =CO2
    = JST =SCAL
    = STA =EFFG&1
    = STA ='750                     =STORE EFF. SCALED CO2 FOR CIRC
    = LDA =CO2
    = SKG =SXTY                     =IS CO2 GREATER THAN 60
    = JMP =*&2                      =NO
    = JMP =R71                      =YES
    = LDA ='764                     =PICK UP F3(O2)
    = SUB =ONE
    = JPL =*&2                      =IS RESULT NEGATIVE,NO
    = JMP =R71                      =YES
    = TAB =
     = MPY =ONSX               =MULTIPLY BY 196
     = LLS =11
     = JMP =*&2
R71  = CRA =
     = ADD =CO2
     = TAB =
     = JST =SCAL
     = STA =EFFG&1             =STORE F3''(O2)
     = LDA ='724               =PICK UP EFF O2 FOR HYPERVENTILATION
     = SKG =O2C1               =EFF O2 ABOVE 52
     = JMP =R7D                =NO
     = SKG =O2C2               =YES,IS EFF O2 ABOVE 55
     = JMP =R7A                =NO
     = LDA =O2C2               =YES
     = STA ='724               =LIMIT EFF O2AT 55
     = JMP =R7D
R7A  = NOP =
     = SUB =OLDC               =SUBTRACT OLD EFF O2
     = JZE =R7E                =IS DIFF. ZERO,YES
     = JPL =R7C                =NO,IS DIFF. POSITIVE,YES
     = LDA =O2TL               =NO,PUT IN LOW TIME CONST.
R7B  = STA =TLG
     = JMP =R7E
R7C  = LDA =O2TH               =PUT IN HIGH TIME CONST.
     = JMP =R7B
R7D  = LDA =O2TN               =PUT IN NORMAL TIME CONST.
     = JMP =R7B
R7E  = NOP =
     = LDB ='724               =PICK UP EFF O2
     = STB =OLDC               =UPDATE OLD EFF O2
     = LDB ='724
     = JST =SCAL
     = STA =EFFG&2
     = STA =EFFG&3             =STORE EFF. O2 FOR FUNC
     = STA ='747               =STORE EFF. O2 FOR CIRC
     = LDX =-4,1
R8   = LDA =EFFG&4,1
     = LDB =GFAC&4,1
     = CALL=FUBR               =GET F1 AND F2 FUNCTIONS FOR O2 AND CO2
     = STA =BACO&4,1
     = JXI =R8,1
     = LDA =BRO2
     = STA ='775               =STORE F1(O2) IN XCEL
     = LDB =BRCO
     = MPY =BRO2
     = LLS =14                    =CALCULATE BR AT B8
     = STA =BR
     = LDA =BACO
     = ADD =BAO2
     = JPL =*&2                   =IS BREATHING AMP. NEG.,NO
     = CRA =                      =YES
     = TAB =
     = MPY =BRO2                  =MULTIPLY BY O2 RATE MULTIPLIER
     = LLS =14
     = STA =BA                    =CALCULATE BA AT B8
     = LDA =HYFL
     = JZE =R9                    =IS HYSTERESIS FLAG SET,NO
     = LDA ='753                  =YES,PICK UP ANEST. LEVEL
     = SKG =AHYL                  =IS A LEVEL STILL ABOVE RECOVERY POINT
     = JMP =*&2                   =NO
     = JMP =R11                   =YES
     = LDA ='713                  =PICK UP DES-EFF. SUCC.
     = SKG =SHYL                  =IS DES STILL ABOVE RECOVERY POINT
     = JMP =*&2                   =NO
     = JMP =R11                   =YES
     = CRA =
     = STA =HYFL                  =RESET HYSTERESIS FLAG
R8A  = LDA =BA
     = STA =BAIN                  =SET BA LAG INPUT TO CALC. VALUE
     = LDA =BR
     = STA =BRIN                  =SET BR LAG INPUT TO CALC. VALUE
     = JMP =R11
R9   = NOP =
     = LDA ='753
     = SKG =AHYH                  =IS A LEVEL ABOVE THRESHOLD
     = JMP =*&2                   =NO
     = JMP =R10                   =YES
     = LDA ='713
     = SKG =SHYH                  =IS DES ABOVE THRESHOLD
     = JMP =R8A                   =NO
R10  = NOP =                      =YES
     = IRX =HYFL                  =SET HYST. FLAG
     = CRA =
     = STA =BAIN
     = STA =BRIN                  =SET LAG INPUTS TO ZERO
R11  = NOP =                      =START LAG FUNCTIONS
     = LDA =TCHY
     = STA =R12
     = LDA =BAIN
     = LDB =BALA
```

```
    = CALL=LAG
R12 = PZE =**
    = STA =BA                  =STORE LAG OUTPUT AS BA
    = LDA =TCHY&1
    = STA =R13
    = LDA =BRIN
    = LDB =BRLA
    = CALL=LAG
R13 = PZE =**
    = STA =BR                  =STORE LAG OUTPUT IN BR
    = TAB =
    = MPY =BA                  =FORM VR FOR BREATHING PRINT
    = LLS =5                   =PUT BP AT B11
    = JZE =RBP1                =HAS BREATHING STOPPED,YES
    = LDA =BPFL                =NO
    = JZE =RBP2                =IS BREATHING PRINT FLAG SET,NO
    = LDA ='76C                =YES,GET TIME
    = ORA =BRCC&1              =INSERT BREATHING STARTED CODE
    = CALL=PSTR                =STORE PRINT ENTRY
    = CRA =
    = STA =BPFL                =RESET PRINT FLAG
    = JMP =RBP2
RBP1= LDA =BPFL
    = JZE =*&2                 =IS BREATHING PRINT FLAG SET,NO
    = JMP =RBP2                =YES
    = LDA ='76C                =GET TIME
    = ORA =BRCC                =INSERT BREATHING STOPPED FLAG
    = CALL=PSTR                =STORE PRINT ENTRY
    = STX =BPFL                =SET PRINT FLAG
RBP2= NOP =
    = NOP =                    =START INSTANT. VR CALC.
    = LDA ='771                =PICK UP RIGHT LUNG POS.
    = ADD ='772                =ADD LEFT LUNG POS.
    = ADD ='773                =ADD SMALL RIGHT LUNG POS.
    = STA =NVOL                =STORE NEW TOTAL VOLUME
    = SUB =OVOL                =SUBTRACT OLD VOLUME
    = JPL =R13A                =IS DIFFERENCE POSITIVE,YES
    = CRA =                    =NO
    = STA =IVR                 =MAKE INST. VR ZERO DURING EXHALE
    = JMP =R13B
R13A= TAB =
    = MPY =PRMN                =MULTIPLY BY RECIPR. TIME INTERVAL
    = LLS =8
    = SKS ='20                 =IS S.S. 5 SET
    = CRA =                    =YES,MAKE INST. VR ZERO
```

```
      = STA =IVR               =STORE INST. VR AT B11
      = LDA =IVR
      = LDB =IVLA
      = CALL=LAG               =PERFORM LAG ON INST. VR
      = DEC =.01B0
      = STA =IVR
  R13B= LDA =NVOL
      = STA =OVOL              =UPDATE OLD LUNG VOLUME
      = LDB =*740              =PICK UP CIRCULATION AT B11
      = MPY =KN&4              =MULTIPLY BY 1/6.5 B0
      = TAB =
      = MPY =IVR
      = LLS =11
      = STA =IVRC              =STORE INST. VR WITH CIRC.
      = LDX =-4,1              =START FLOW PRINT ROUTINE
  R13C= LDA =CFLO&4,1          =GET CURRENT FLOW
      = SUB =LSTP&4,1          =SUBTRACT LAST PRINT
      = ANA =AVMK              =MAKE DIFF. ABSOLUTE
      = SKG =FSPC&4,1          =IS DIFF. GREATER THAN FULL-SCALE PERC.
      = JMP =*&2               =NO
      = JMP =R13D              =YES
      = LDA =LSTP&4,1
      = STA =LSTT&4,1          =RESET LAST THRESHOLD
      = JMP =R13H              =GO RESET TIMER
  R13D= LDA =CFLO&4,1
      = SUB =LSTT&4,1
      = ANA =AVMK              =FORM DIFF. OF FLOW AND LAST THRESH.
      = SKG =FSPC&4,1          =IS DIFF. GREATER THAN FULL-SCALE PERC.
      = JMP =R13E              =NO
      = LDA =UNO               =YES
      = STA =TIMR&4,1          =START TIMER
      = LDA =CFLO&4,1
      = STA =LSTT&4,1          =UPDATE LAST THRESHOLD
      = JMP =R13I
  R13E= LDA =TIMR&4,1
      = JZE =R13I              =IS TIMER RUNNING,NO
      = SKG =TLIM              =YES,HAS TIMER REACHED LIMIT
      = JMP =*&2               =NO
      = JMP =R13G              =YES
      = ADD =UNO               =STEP TIMER
  R13F= STA =TIMR&4,1
      = JMP =R13I
  R13G= LDA =*760              =GET TIME
      = ORA =CODE&4,1          =INSERT CODE
      = LDB =CFLO&4,1          =PUT VALUE IN B
```

```
    = STB =LSTP&4,1             =UPDATE LAST PRINT
    = CALL=PSTR                 =STORE PRINT ENTRY
R13H= CRA =
    = JMP =R13F                 =RESET TIMER
R13I= JXI =R13C,1
R14 = NOP =                     =START LUNG POSITION CALC.
    = LDB =BA                   =PICK UP BA AT B8
    = MPY =BR                   =MULTIPLY BY BR AT B3
    = LLS =8                    =SHIFT BINARY POINT TO B8
    = TAB =
    = MPY =KS
    = STA =SLPE                 =CALCULATE SLOPE AT B8
    = JZE =R14A                 =IS SLOPE ZERO, YES
    = LDA =EXFL                 =NO,PICK UP EXHALE FLAG
    = JZE =R14B                 =IS FLAG SET, NO
    = LDA ='744                 =YES, PICK UP LUNG POSITION
    = SKG =SLPE                 =IS LUNG POS. GREATER THAN SLOPE
    = JMP =R14D                 =NO
    = SUB =SLPE                 =SUBTRACT SLOPE
    = JMP =R14E
R14A= IRX =EXFL                 =SET EXHALE FLAG
    = OCP ='1025                =SET EXHALE OC
    = CRA =                     =SET LUNG POS. TO ZERO
    = JMP =R14E
R14B= LDA ='744
R14C= ADD =SLPE                 =ADD SLOPE TO LUNG POS.
    = SKG =BA                   =HAS LUNG POS. REACHED MAX.
    = JMP =R14E
    = LDA =BA
    = STX =EXFL                 =SET EXHALE FLAG
    = OCP ='1025                =SET EXHALE OC
    = JMP =R14E
R14D= OCP =2
    = OTM =DE22                 =RESET EXHALE OC
    = CRA =
    = STA =EXFL                 =RESET EXH. FLAG
R14E= STA ='744
R14F= NOP =
    = LDA =BA
    = STA ='731
    = LDA =BR
    = STA ='732                 =PICK UP INST. VR FOR OUTPUT
    = LDA =IVR
    = STA ='733
    = LDA ='747
    = LDA =EFFG
    = STA ='735                  =PUT EFF. CO2 IN OUTPUT CELL
R15 = LDX =**,1
    = JMP*=R1                    =EXIT
SCAL= JMP =**
    = MPY =KFUN                  =MULTIPLY BY SCALING CONS. FOR FUNC
    = SKG =MAX                   =IS RESULT GREATER THAN MAX
    = JMP =*&2                   =NO
    = LDA =MAX                   =YES
    = ALS =11                    =SHIFT FOR FUNC
    = JMP*=SCAL                  =RETURN
TC  = DEC =10,90,90,67,67,135,33,15,15,449,1340,67
CLG = OCT =0,0,0
TLG = OCT =0,0,0
KC01= OCT =0
TCHY= OCT =0,0
C2TL= OCT =0
C2TH= OCT =0
C2TN= OCT =0
AHYH= DEC =2.5B11
AHYL= DEC =2.33B11
ALFA= OCT =0
APFL= OCT =0
ARCD= OCT =12000000,13000000
AVMK= OCT =37777777
AWBT= OCT =10
BACO= OCT =0
BRCO= OCT =0
BAO2= OCT =0
BRO2= OCT =0
BA  = OCT =0
BAIC= DEC =.425B8
BAIN= OCT =0
BALA= PZE =BALS
BALS= OCT =0
BR  = OCT =0
BRIC= DEC =14.8B8
BRIN= OCT =0
BRLA= PZE =BRLS
BRLS= OCT =0
BPFL= OCT =0
BRCD= OCT =10000000,11000000
CFLO= OCT =0,0,0,0
CODE= OCT =00000000,01000000,02000000,03000000
COIC= DEC =40B8
```

```
COSL= OCT =0
CO2 = OCT =0
CO2E= OCT =0
CO2F= DEC =.4B0
CSL1= OCT =0
CSL2= OCT =0
DE22= OCT =2600
EFFG= OCT =0,0,0,0
EXFL= OC  =0
FSPC= DE  =.3B11,.6B11,.05B11,.05B11
GASI= OCT
GASS= OCT =0
GFAD= PZE =F2C0
    = PZE =F1C0
    = PZE =F202
    = PZE =F102
HYFL= OCT =0
IVR = OCT =0
IVRC= OCT =0
IVLA= PZE =IVLS
IVLS= OCT =0
KCO2= DEC =33B19
KCO3= DEC =1.069B11
KCO4= DEC =.1194B0
KCO5= DEC =.02909B0
KF  = DEC =39.1B11,100B11,100B11
KFUN= DEC =.01B0
KN  = DEC =.08B0,.01385B0,.27B11,6.5B10,.15384B0,0
KS  = OCT =0
KSO = DEC =.03333B0
LCOA= PZE =COSL
LG1S= OCT =0
L1SA= PZE =OSL1
    = PZE =CSL1
    = PZE =NSL1
L2SA= PZE =OSL2
    = PZE =CSL2
    = PZE =NSL2
LSTT= OCT =0,0,C,0
LSTP= OCT =0,0,C,0
MAX = OCT =7777
MKBT= OCT =20
NSL1= OCT =0
NSL2= OCT =0
NVOL= OCT =0
```

```
OVOL= OCT =0
OLDO= OCT =0
O2IO= DEC =50B11
O2IF= DEC =.5B0
O2C1= DEC =52B11
O2C2= DEC =55B11
O2C3= DEC =1.407B8
OSIC= DEC =50B10
OSL1= OCT =0
OSL2= OCT =0
ONE = DEC =1B11
ONSX= DEC =196B11
SXTY= DEC =60B11
PCO2= DEC =.2B0
PGAS= DEC =.2B0,0,0
PRMN= DEC =150B11
SHYH= DEC =22B11
SHYL= DEC =11.0B11
SLPE= OCT =0
TCO = OCT =0
TIMR= OCT =0,0,0,0
TLIM= DEC =100
UNO = DEC =1
VRIC= DEC =6.29B11
ZERO= OCT =0
F1C = PZE =F1CO
F2C = PZE =F2CO
F1O = PZE =F1O2
F2O = PZE =F2O2
F1CO= DEC =15
    = DEC =31.0B11,00.0B11,32.5B11,06.0B11,34.5B11,13.6B11
    = DEC =36.0B11,14.2B11,40.0B11,14.8B11,42.5B11,15.2B11
    = DEC =46.0B11,16.0B11,48.0B11,16.8B11,50.0B11,18.1B11
    = DEC =70.0B11,38.5B11,72.0B11,39.7B11,74.0B11,39.8B11
    = DEC =76.0B11,39.0B11,85.0B11,20.0B11,94.0B11,00.0B11
F2CO= DEC =21
    = DEC =00.0B11,0.00B11,19.0B11,0.14B11,30.0B11,0.28B11
    = DEC =40.0B11,0.43B11,45.0B11,0.54B11,48.0B11,0.61B11
    = DEC =52.0B11,0.76B11,57.0B11,1.00B11,59.0B11,1.14B11
    = DEC =62.0B11,1.48B11,64.0B11,1.69B11,66.0B11,1.84B11
    = DEC =68.0B11,1.96B11,70.0B11,2.00B11,72.0B11,1.96B11
    = DEC =76.0B11,1.76B11,80.0B11,1.48B11.84.0B11,1.18B11
    = DEC =86.0B11,1.01B11,88.0B11,0.83B11,94.7B11,0.00B11
F1O2= DEC =10
    = DEC =00.0B11,0.000B11,02.5B11,0.150B11,05.0B11,0.275B11
    = DEC =07.5B11,0.400B11,10.0B11,0.600B11,12.5B11,0.800B11
    = DEC =15.0B11,0.980B11,16.0B11,0.995B11,17.5B11,1.000B11
    = DEC =20.0B11,1.000B11
F202= DEC =21
    = DEC =00.0B11,-.500B11,02.5B11,-.250B11,05.0B11,&.025B11
    = DEC =07.5B11,&.270B11,09.0B11,&.425B11,10.0B11,&.470B11
    = DEC =11.0B11,&.485B11,12.5B11,&.495B11,15.0B11,&.500B11
    = DEC =17.5B11,&.490B11,20.0B11,&.430B11,27.5B11,&.255B11
    = DEC =32.5B11,&.137B11,35.0B11,&.080B11,36.0B11,&.060B11
    = DEC =37.5B11,&.040B11,40.0B11,&.025B11,42.5B11,&.013B11
    = DEC =45.0B11,&.005B11,47.5B11,&.002B11,50.0B11,&.000B11
    = NOP =
    = END =R0
```

```
00742 CARDS READ.
*
*    =       =                          =ACTS-MANIKIN ACTUATION SUBROUTINE
CACT= NTRY=A0
ACTS= NTRY=A1
     = REL =
A0   = JMP =**                          =START CLEAR ROUTINE
     = STX =AX,1
     = OCP ='1013
     = OCP =2
     = LDX =-6,1
     = OTM =DEC0&6,1                    =RESET ACTUATIONS WITH DECODER
     = JXI =*-1,1
     = CRA =
     = STA =IRFL                        =RESET INCREASE FLAG
     = STA =AIRF
     = STA =ARFL
     = STA =BUFL
     = STA =SCFL
     = STA =DFLG
     = STA =DPS
     = STA =DPD
     = STA =DPR
     = STA =STFL                        =CLEAR FOR DELTA PS,PD,AND PR
     = STA =CUV
     = STA =CUV&1
     = STA =CUV&2
     = STA =CUV&3                       =CLEAR FOR MANUAL SWITCHES
     = STA =INFL                        =CLEAR AIRWAY INSERTED FLAG
     = STA =SAFL                        =CLEAR AIRWAY SENS. FLAG
     = STA =BKFL                        =CLEAR BUCKING FLAG
     = STA =LRFL                        =CLEAR LARYNGOSPASM FLAG
     = STA =TBUK                        =CLEAR BUCKING TIMER
     = STA =MFFL
     = STA =FSFL                        =CLEAR FASCIC. FLAGS
     = STA =FTIM                        =CLEAR FASCIC. TIME
     = STA ='673                        =INITIALIZE EYELID TENSION
     = STA ='675                        =INITIALIZE COLOR SIGNAL
     = LDX =-10,1
     = CRA =
     = STA =ACFL&10,1                   =CLEAR ACTUATION FLAGS
     = STA =PRFL&10,1                   =CLEAR PRINT FLAGS
     = JXI =*-2,1
     = NOP =
     = LDA =TJIC
```

```
      = STA ='672                     =INITIALIZE JAW TENSION
      = LDA =DEIC
      = STA ='674                     =INITIALIZE PUPIL DILATION
      = LDA =FHIC
      = STA ='676                     =INITIALIZE FOREHEAD WRINKLING
      = LDA =LCIC
      = STA ='677                     =INITIALIZE VOCAL CORD
AX    = LDX =**,1                     =RESTORE INDEX
      = JMP*=A0                       =RETURN
*****************************************************************
A1    = JMP =**
      = STX =AXX,1                    =STORE INDEX
      = LDA ='763
      = JZE =A29                      =IS OP FLAG SET,NO, GO TO BLINK
      = LDA ='774                     =PICK UP AIRWAY POSITION
      = SKG =AIRM                     =IS IT ABOVE MINIMUM
      = JMP =A1A                      =NO
      = LDA =AWIF                     =YES
      = JZE =*+2                      =IS AIRWAY INSERTION FLAG SET,NO
      = JMP =A2                       =YES
      = STX =AWIF                     =NO,SET FLAG
      = LDA =ARFL
      = JZE =*+2                      =IS AIRWAY FLAG SET,NO
      = JMP =A2                       =YES
      = STX =ARFL                     =SET FLAG
      = JMP =A4                       =GO CHECK A LEVEL
A1A   = CRA =
      = STA =AWIF                     =RESET AIRWAY INSERTION FLAG
A2    = LDA =ACFL65                   =GET BUCKING ACT FLAG
      = JZE =A3                       =IS BUCKING TAKING PLACE,NO
      = LDA =BUFL                     =YES
      = JZE =*+2                      =IS BUCKING FLAG SET,NO
      = JMP =A5                       =YES
      = STX =BUFL                     =SET FLAG
      = JMP =A4                       =GO CHECK A LEVEL
A3    = LDA =STFL
      = JZE =*+2                      =IS SUCC. TEST FLAG SET,NO
      = JMP =A5                       =YES
      = LDA ='713                     =PICK UP EFF. SUCC.
      = SKG =DESM                     =IS IT ABOVE MIN. LEVEL
      = JMP =A5                       =NO
      = STX =STFL                     =YES,SET SUCC. TEST FLAG
      = LDA ='753                     =PICK UP ANEST. LEVEL
      = SKG =AMIN                     =IS IT ABOVE MIN. LEVEL
      = JMP =*+2                      =NO
      = JMP =A5                 =YES
      = LDA =SCFL
      = JZE =*&2                =IS SUCC. FLAG SET,NO
      = JMP =A5                 =YES
      = STX =SCFL               =SET SUCC. FLAG
A4    = LDA ='753               =GET ANEST. LEVEL
      = SKG =ATHR               =IS A LEVEL GREATER THAN THRESH.
      = JMP =A7                 =NO,GO CALCULATE DELTAS
A5    = LDA =IRFL               =GET INCREASE FLAG
      = JZE =A5A                =IS IT SET,NO
      = LDX =-3,1               =YES
      = LDA =DPS&3,1
      = ADD =DSPS&3,1
      = STA =DPS&3,1            =INCREASE DELTA
      = JXI =*-3,1
      = SKG =DPRB               =HAS DELTA REACHED LIMIT
      = JMP =A10                =NO
      = CRA =
      = STA =IRFL               =RESET INCREASE FLAG
      = JMP =A10
A5A   = NOP =
      = LDA =ACFL&5             =GET BUCKING ACT FLAG
      = JZE =*&2                =IS BUCKING ON,NO
      = JMP =A11                =YES,GO TO EXIT
      = LDA =DFLG               =PICK UP DELTAS SUM
      = JZE =*&2                =ARE ALL DELTAS ZERO,YES
      = JMP =A6                 =NO
      = CRA =
      = STA =ARFL
      = STA =BUFL
      = STA =SCFL               =RESET FLAGS
      = STA =DPSB
      = STA =DPDB
      = STA =DPRB               =CLEAR DELTA LIMITS
      = JMP =A11                =GO TO EXIT
A6    = LDA =DPS
      = SUB =DSPS               =DECREASE DELTA PS
      = JPL =*&2                =IS IS POSITIVE,YES
      = CRA =                   =NO,SET DELTA TO ZERO
      = STA =DPS
      = LDA =DPD
      = SUB =DSPD               =DECREASE DELTA PD
      = JPL =*&2
      = CRA =
      = STA =DPD
      = LDA =DPR
      = SUB =DSPR                  =DECREASE DELTA PR
      = JPL =*&2
      = CRA =
      = STA =DPR
      = JMP =A10
A7    = LDX =-3,1                  =START DELTA CALC.
A8    = LDB ='753                  =PICK UP ANEST. LEVEL
      = MPY =AMLT&3,1
      = LLS =11
      = STA =TMP
      = LDA =PCON&3,1
      = SUB =TMP                   =CALCULATE DELTA
      = SKG =DPSB&3,1              =IS NEW DELTA LIMIT GREATER THAN OLD
      = JMP =A9                    =NO
      = STA =DPSB&3,1              =YES,REPLACE OLD WITH NEW
      = LDB =DPSB&3,1
      = MPY =DCCN                  =CALCULATE DECREMENT
      = STA =DSPS&3,1
      = LDB =DPSB&3,1
      = MPY =UPCN
      = STA =USPS&3,1              =CALCULATE INCREMENTS
A9    = JXI =A8,1
      = STX =IRFL                  =SET INCREASE FLAG
A10   = LDA =DPS
      = ADD =DPD
      = ADD =DPR
      = STA =DFLG                  =FORM SUM OF DELTAS
***************************************************************************
A11   = NOP =
      = NOP =                      =START MANUAL SWITCH ROUTINE
      = LDA ='766                  =PICK UP CSW
      = ARS =10
      = STA =TEMP
      = LDX =-4,1
A12   = LDA =TEMP
      = ARS =2
      = STA =TEMP
      = ANA =SWMK                  =STRIP OUT SWITCH BITS
      = ADD =MANU                  =FORM ADDRESS FOR SWITCH POSITION
      = STD =*&1
      = JMP*=**
MANO= NOP =                        =NEUTRAL SWITCH POSITION
      = LDA =CUV&4,1               =PICK UP CURRENT VALUE
      = ANA =ABMK                  =MAKE VALUE ABSOLUTE
      = SKG =NUCH&4,1          =IS IT GREATER THAN NEUT. CHANGE
      = JMP =MNOC              =NO
      = LDA =CUV&4,1           =YES
      = JPL =MNOD              =IS CURRENT VALUE POSITIVE,YES
      = ADD =NUCH&4,1          =NO,ADD NEUT. CHANGE
 MNOA= STA =CUV&4,1            =STORE CURRENT VALUE
 MNOB= JXI =A12,1              =ARE ALL SWITCHES CHECKED,NO
      = JMP =A13               =YES,JUMP TO CONTINUE
 MNOC= CRA =
      = JMP =MNOA
 MNOD= SUB =NUCH&4,1           =SUBTRACT NEUT. CHANGE
      = JMP =MNOA
 MAN1= LDA =CUV&4,1
      = ADD =UDCH&4,1          =INCREASE  CURRENT VALUE
      = SKG =PLMT&4,1          =IS VALUE GREATER THAN POS. LIMIT
      = JMP =MNOA              =NO
      = LDA =PLMT&4,1          =YES PICK UP LIMIT
      = JMP =MNOA
 MAN2= LDA =CUV&4,1
      = SUB =UDCH&4,1          =DECREASE CURRENT VALUE
      = SKG =NLMT&4,1          =IS VALUE GREATER THAN NEG. LIMIT
      = JMP =*&2               =NO
      = JMP =MNOA              =YES
      = LDA =NLMT&4,1          =PICK UP NEG. LIMIT
      = JMP =MNOA
 MAN3= ADX =8,1                =SET UP HALT CODE
      = STX =*&1,1
      = HLT =**                =ERROR HALT
      = ADX =-8,1              =RESTORE INDEX
      = JMP =MNOB              =CONTINUE PROGRAM
 A13  = LDA =CUV&1
      = STA ='671              =STORE CO2 SWITCH CHANGE
      = LDA =CUV&2
      = ADD =DPR
      = STA ='746              =STORE PULSE RATE CHANGE
      = LDA =CUV&3
      = ADD =DPD
      = STA ='745              =STORE DIASTOLIC PRESSURE CHANGE
      = LDA =CUV&3
      = ADD =DPS
      = STA ='670              =STORE SYSTOLIC PRESSURE CHANGE
************** ********************************************************
 A14  = NOP =                  =START AIRWAY INSERTION TEST
      = LDA ='774
      = SKG =AIRT              =IS AIRWAY POS. GREATER THAN THRESH.
```

```
     = JMP =A15                 =NO
     = LDA ='753                =YES,PICK UP ANEST. LEVEL
     = SKG =ATH1                =IS IT GREATER THAN THRESH.
     = JMP =*&2                 =NO
     = JMP =A14A                =YES
     = LDA ='713                =PICK UP EFF. SUCC.
     = SKG =STH1                =IS IT GREATER THAN THRESH.
     = JMP =*&3                 =NO
A14A= STX =INFL                 =YES,SET INSERTED FLAG
     = JMP =A17
     = LDA =INFL
     = JZE =A14B                =IS INSERTED FLAG SET,NO
     = LDA ='753                =YES,GET ANEST. LEVEL
     = SKG =ATH2                =IS A LEVEL ABOVE LOWER THRESH.
     = JMP =*&2                 =NO
     = JMP =A17                 =YES
     = LDA ='713                =GET EFF. SUCC.
     = SKG =STH2                =IS IT GREATER THAN HIGH THRESH.
     = JMP =*&2                 =NO
     = JMP =A17                 =YES
A14B= STX =SAFL                 =SET SENS. TO AIRWAY FLAG
     = JMP =A18
A15  = SKG =AIRM                =IS AIRWAY POS. GREATER THAN MIN.
     = JMP =*&2                 =NO
     = JMP =A18                 =YES
A16  = CRA =
     = STA =INFL                =RESET INSERTED FLAG
A17  = CRA =
     = STA =SAFL                =RESET AIRWAY SENS. FLAG
*************************************************************************
A18  = NOP =                    =START BUCKING ROUTINE
     = LDA ='724                =GET EFF. 02
     = SKG =02MN                =IS IT GREATER THAN MIN.
     = JMP =BUK1                =NO,GO TO STOP BUCKING
     = LDA ='766                =YES,GET CSW
     = ARS =1
     = ANA =SWMK                =STRIP OUT SWITCH BITS
     = ADD =BKAD                =FORM SWITCH POS. ADDRESS
     = STD =*&1
     = JMP*=**
BUK0= LDA =BKFL                 =GET MAN. BUCKING FLAG
     = JZE =*&2                 =IS IT RESET,YES
     = JMP =BUK2                =NO
     = LDA =SAFL
     = JZE =BUK1                =IS SENS. AIRWAY FLAG SET,NO
```

```
BKOA= STX =ACFL&5               =SET BUCKING ACT FLAG
    = LDA =TBUK
    = SKN =TBK2                 =IS IT TIME TO STOP BUCKING
    = JMP =*&2                  =YES
    = JMP =BKOB                 =NO
    = CRA =
    = STA =TBUK                 =CLEAR BUCKING TIMER
    = JMP =BK1A
BKOB= SKN =TBK1                 =IS IT TIME TO TURN ON BUCKING
    = JMP =BKOC                 =YES
    = IRX =TBUK                 =NO,STEP TIMER
BKOC= OCP ='1021                =TURN ON BUCKING
    = JMP =*-3                  =GO STEP TIMER
BUK1= OCP =2
    = CRA =
    = STA =BKFL                 =CLEAR BUCKING FLAG
    = STA =ACFL&5               =RESET BUCKING ACT FLAG
BK1A= OTM =DEC0&4               =DECODER 15,STOP BUCKING
    = JMP =A19
BUK2= LDA ='753                 =GET ANEST. LEVEL
    = SKG =ATHR                 =IS IT GREATER THAN MAX. THRESH.
    = JMP =*&2                  =NO
    = JMP =BUK1                 =YES
    = LDA ='713                 =GET EFF. SUCC.
    = SKG =STH3                 =IS IT GREATER THAN SUCC. MAX.
    = JMP =*&2                  =NO
    = JMP =BUK1                 =YES
    = STX =BKFL                 =SET BUCKING FLAG
    = JMP =BKOA
BUK3= HLT ='10                  =ERROR HALT,BITS 21 AND 22 ON
**********************************************************************
A19 = NOP =                     =START LARYNGOSPASM ROUTINE
    = LDA ='724                 =GET EFF. O2
    = SKG =O2MN                 =IS IT GREATER THAN O2 MIN.
    = JMP =LAR1                 =NO
    = LDA ='766                 =YES,GET CSW
    = ARS =5
    = ANA =SWMK                 =STRIP OUT SWITCH BITS
    = ADD =LRAD                 =FORM SWITCH POS. ADDRESS
    = STD =*&1
    = JMP*=**
LARO= LDA =LRFL                 =GET MANUAL LARY. FLAG
    = JZE =*&2
    = JMP =LAR2
    = LDA =SAFL
```

```
      = JZE =LAR1               =IS SENS. AIRWAY FLAG SET,NO
      = JMP =LR2B
LAR1= OCP =2
      = OTM =DECO&2             =DECODER 13
      = CRA =
      = STA =LRFL               =RESET LARYG. FLAG
      = STA =ACFL&6             =RESET LARY. ACT FLAG
      = JMP =A20
LAR2= LDA ='753                 =GET ANEST. LEVEL
      = SKG =ATHR               =IS IT GREATER THAN MAX.
      = JMP =*&2                =NO
      = JMP =LAR1               =YES
      = LDA ='713               =GET EFF. SUCC.
      = SKG =STH3               =IS IT GREATER THAN MAX.
      = JMP =*&2                =NO
      = JMP =LAR1               =YES
LR2A= STX =LRFL                 =SET LARY. FLAG
LR2B= OCP ='1043                =START LARYNGOSPASM
      = STX =ACFL&6             =SET LARY. ACT FLAG
      = JMP =A20
LAR3= HLT ='11                  =ERROR HALT,BITS 17 AND 18 ON
*************************************************************************
A20 = NOP =                     =START FASCICULATION ROUTINE
      = LDA ='724               =GET EFF. O2
      = SKG =O2MN               =IS IT GREATER THAN MIN.
      = JMP =A22                =NO,GO TO STOP FASC.
      = LDA =FSFL               =YES
      = JZE =*&2                =HAS FASCIC. OCCURRED,NO
      = JMP =A24                =YES,EXIT
      = LDA =MFFL
      = JZE =*&2                =IS FASCIC. TAKING PLACE,NO
      = JMP =A21                =YES
      = LDA ='713               =GET EFF. SUCC.
      = SKG =STH1               =IS IT GREATER THAN THRESH.
      = JMP =A24                =NO,EXIT
      = LDA ='776               =GET INJECTED SUCC.
      = LDX =-3,1
      = SKG =SUCI&3,1           =IS INJ. SUCC. GREATER THAN TABLE
      = JMP =*&4                =NO
      = LDA =TIMF&3,1           =YES,GET FASC. TIME
      = NOP =
      = JMP =*&3
      = JXI =*-5,1
      = LDA =TIMF&3
      = STA =FTMX               =SET MAX. FASC. TIME
```

```
    = STX =MFFL                 =SET FASC. FLAG
    = STX =ACFL&8               =SET FASC. FLAG
    = OCP ='1020                =START FASC.
    = CRA =
    = STA =FTIM                 =RESET TIMER
    = JMP =A24                  =EXIT
A21 = NOP =
    = LDA =FTIM                 =GET TIMER
    = SKG =FTMX                 =IS TIME LIMIT REACHED
    = JMP =A23                  =NO
    = STX =FSFL                 =YES,SET FASC. OCCURRED FLAG
A22 = OCP =2
    = OTM =DECC&3               =STOP FASC.
    = CRA =
    = STA =MFFL                 =RESET FASC. FLAG
    = STA =ACFL&8               =RESET FASC. FLAG
    = JMP =A24                  =EXIT
A23 = IRX =FTIM                 =STEP TIMER
**************************************************************************
A24 = NOP =                     =START ARRHYTHMIA ROUTINE
    = LDA ='734                 =GET CO2
    = SKG =CO2A                 =IS IT ABOVE THRESH.
    = JMP =*&2                  =NO
    = JMP =A25                  =YES
    = LDA ='766                 =GET CSW
    = ANA =AYMK                 =STRIP OUT ARRHY. SWITCH BIT
    = JZE =*&5                  =IS BIT ON,NO
    = LDA ='734                 =YES,GET CO2
    = SKG =CO2M                 =IS IT ABOVE MIN.
    = JMP =*&2                  =NO
    = JMP =A25                  =YES
    = OCP =2
    = OTM =DECC&5               =STOP ARRHY.
    = CRA =
    = STA =ACFL&9               =CLEAR ARRY. FLAG
    = JMP =A26                  =EXIT
A25 = OCP ='1022                =START ARRHY.
    = STX =ACFL&9               =SET ARRY. FLAG
**************************************************************************
A26 = OCP =2                    =START BRONCHUS BLOCK ROUTINE
    = CRA =
    = STA =ACFL&3
    = STA =ACFL&4               =CLEAR BOTH BRONCHUS BLOCK FLAGS
    = LDA ='766                 =GET CSW
    = ARS =7
    = ANA =SWMK                        =STRIP OUT SWITCH POSITIUN BITS
    = ADD =BRAD                        =FORM ADDRESS
    = STD =*&1
    = JMP*=**
BRB0= NOP =
    = OTM =DEC0
    = OTM =DEC0&1                      =RESET RIGHT AND LEFT BRON. BLKS.
    = JMP =A27                         =EXIT
BRB1= OCP ='1026                       =START RIGHT BRON. BLK.
    = STX =ACFL&3                      =SET RIGHT BB FLAG
    = OTM =DEC0&1                      =STOP LEFT BRON. BLK.
    = JMP =A27                         =EXIT
BRB2= OTM =DEC0                        =STOP RIGHT BRON. BLK.
    = OCP ='1027                       =START LEFT BRON. BLK.
    = STX =ACFL&4                      =SET LEFT BB FLAG
    = JMP =A27
BRB3= OCP ='1026
    = OCP ='1027                       =START RIGHT AND LEFT BR. BLK.
    = STX =ACFL&3                      =SET RIGHT BB FLAG
    = STX =ACFL&4                      =SET LEFT BB FLAG
*******************************************************************************
A27 = SKS ='60000                      =START LIP PINCHED ROUTINE,IS S.L. SET
    = JMP =*&2                         =YES
    = NOP =                            =NO
    = SKS ='60000                      =IS S.L. 200 STILL SET
    = JMP =*&4                         =YES
    = CRA =                            =NO
    = STA =ACFL&7                      =CLEAR LP FLAG
    = JMP =A28
    = STX =ACFL&7                      =SET LP FLAG
*******************************************************************************
A28 = NOP =                            =START JAW TENSION ROUTINE
    = LDB ='713                        =GET EFF. SUCC.
    = MPY =TJCN
    = STA =TJTM
    = LDA =ONE
    = SUB =TJTM
    = STA =TJTM
    = LDB ='753                        =GET ANEST. LEVEL
    = MPY =TJCN&1
    = STA =TJTM&1
    = LDA =ONE
    = SUB =TJTM&1
    = STA =TJTM&1
    = LDB ='775                        =GET F1(O2)
```

```
   = MPY =TJTM&1
   = LRS =12                      =PUT PARTIAL RESULT IN B AT B11
   = MPY =TJTM
   = LRS =12
   = MPY =TJFS
   = LLS =11                      =CALC. TJ AT B11
   = JPL =*&2                     =IS CALC. TJ POSITIVE, YES
   = CRA =                        =NO
   = ADD =CUV                     =ADD SWITCH INCREMENT
   = JPL =*&2                     =IS TJ POSITIVE,YES
   = CRA =                        =NO,MAKE TJ ZERO
   = SKG =TJFS                    =IS TJ GREATER THAN FULL SCALE
   = JMP =*&2                     =NO
   = LDA =TJFS                    =YES
   = STA ='672                    =STORE TJ IN XCEL
*****************************************************************
A29 = NOP =                       =START EYELID TENSION ROUTINE
    = LDA ='724                   =GET EFF. O2
    = SKG =O2MN                   =IS IT GREATER THAN MIN.
    = JMP =A31                    =NO
    = LDA =SAFL
    = JZE =*&2                    =IS AIRWAY SENS. FLAG SET,NO
    = JMP =A32                    =YES
    = LDA ='713                   =GET EFF. SUCC.
    = SKG =TECN&4                 =IS IT GREATER THAN THRESH.
    = JMP =*&2                    =NO
    = JMP =A31                    =YES
    = LDA ='753                   =GET ANEST. LEVEL
    = SKG =ATE1                   =IS A LEVEL ABOVE MAX.
    = JMP =*&2                    =NO
    = JMP =A31                    =YES
    = SKG =ATE2                   =IS A LEVEL ABOVE MIN.
    = JMP =A29A                   =NO
    = LDB ='753                   =GET ANEST. LEVEL
    = MPY =TECN
    = STA =TETM
    = LDA =TECN&1
    = SUB =TETM
    = TAB =
    = MPY =TEFS
    = LLS =11
    = JMP =A33
 A29A= SKG =TECN&5                =IS A LEVEL ABOVE BLINK THRESH.
    = JMP =*&2                    =NO
    = JMP =A30                    =YES
    = LDA =TBLN                        =GET BLINK TIMER
    = SKG =TBL1                        =TIME TO START BLINK
    = JMP =*&2                         =NO
    = JMP =A29B                        =YES
    = IRX =TBLN                        =STEP TIMER
    = CRA =
    = JMP =A33
A29B= SKG =TBL2                        =TIME TO STOP BLINK
    = JMP =*&2                         =NO
    = JMP =A29C                        =YES
    = IRX =TBLN                        =STEP TIMER
    = LDA =TEFS                        =MAKE TE FULL SCALE
    = JMP =A33
A29C= CRA =                            =STOP BLINK
    = STA =TBLN                        =RESET TIMER
    = JMP =A33
A30 = LDB ='753                        =GET ANEST. LEVEL
    = MPY =TECN&2
    = LRS =12                          =PARTIAL RESULT IN B AT B11
    = MPY =TEFS
    = LLS =11
    = JMP =A33
A31 = LDB =TECN&3
    = MPY =TEFS
    = JMP =A33
A32 = LDA =TEFS
A33 = STA ='673                        =STORE EYELID TENSION
    = LDA ='763                        =GET OP FLAG
    = JZE =AXX                         =IS OP FLAG SET,NO
*******************************************************************
A34 = NOP =                            =START PUPIL DILATION ROUTINE
    = LDA ='775                        =GET F1(02)
    = ADD =DECN
    = STA =DETM
    = CRA =
    = TAB =                            =CLEAR B
    = LDA =DECN&1                      =GET CONST. AT B14
    = DIV =DETM                        =DIVIDE BY B11
    = STB =DETM                        =STORE QUOTIENT AT B3
    = LDA ='753                        =GET ANEST. LEVEL
    = SKG =DECN&2                      =IS A LEVEL ABOVE THRESHOLD
    = JMP =A35                         =NO
    = LDA =DECN&3                      =YES
    = SUB ='753
    = JMP =A36
```

```
A35 = LDA =DEIC
A36 = TAB =                           =FACTOR AT B11
    = MPY =DETM                       =FORM PRODUCT AT B14
    = LLS =3                          =DE AT B11
    = JPL =*&2                        =IS RESULT POSITIVE,YES
    = CRA =                           =NO,MAKE DE ZERO
    = STA ='674                       =STORE PUPIL DILATION IN XCEL
*********************************************************************
A37 = NOP =                           =START COLOR SIGNAL ROUTINE
    = LDA ='724                       =GET EFF. O2
    = SKG =CCCN                       =IS O2 GREATER THAN THRESH.
    = JMP =*&3                        =NO
    = CRA =                           =YES,MAKE COLOR SIGNAL ZERO
    = JMP =A38
    = LDA =CCCN
    = SUB ='724
    = TAB =
    = MPY =CCCN&1
    = TAB =
    = MPY =CCFS
    = LLS =11                         =RESULT AT B11
A38 = NOP =
    = STA ='675                       =STORE COLOR SIGNAL IN XCEL
*********************************************************************
A39 = NOP =                           =START FOREHEAD WRINKLE ROUTINE
    = LDA ='724                       =GET EFF. O2
    = SKG =O2MN                       =IS IT GREATER THAN MIN
    = JMP =A40                        =NO
    = LDA =SAFL                       =YES
    = JZE =*&3                        =IS AIRWAY SENS. FLAG SET,NO
    = LDA =FHFS                       =YES
    = JMP =A41
    = LDA =ACFL&5
    = JZE =*&2                        =IS BUCKING FLAG SET,NO
    = JMP =*-4                        =YES
    = LDA ='713                       =GET EFF. SUCC.
    = SKG =FHCN                       =IS IT GREATER THAN THRESH.
    = JMP =*&3                        =NO
    = CRA =                           =YES,MAKE FH ZERO
    = JMP =A41
    = LDA ='753                       =GET ANEST. LEVEL
    = SKG =FHCN&1                     =IS IT GREATER THAN MAX.
    = JMP =*&2                        =NO
    = JMP =*-5                        =YES,GO CLEAR FH
    = SKG =FHCN&2                     =IS A LEVEL GREATER THAN MIN.
    = JMP =A40                          =NO
    = TAB =
    = MPY =FHCN&3
    = ORA =NEGS                         =MAKE SIGN MINUS
    = ADD =FHCN&4
    = TAB =
    = MPY =FHFS
    = LLS =11                           =CALCULATE FH FROM EQUATION
    = JMP =A41
A40 = LDA =FHIC
A41 = STA ='676                         =STORE FOREHEAD WRINK. IN XCEL
******************************************************************************
A42 = NOP =                             =START VOCAL CORD ROUTINE
    = LDA ='724                         =GET EFF. O2
    = SKG =O2MN                         =IS IT GREATER THAN MIN.
    = JMP =A43                          =NO
    = LDA =ACFL&5                       =YES
    = JZE =*&3                          =IS BUCKING FLAG SET,NO
    = LDA =LCFS                         =YES
    = JMP =A45
    = LDA =ACFL&6
    = JZE =*&2                          =IS LARYNGOSPASM FLAG SET,NO
    = JMP =*-4                          =YES
    = LDA ='753                         =GET ANEST. LEVEL
    = SKG =LCCN                         =IS IT GREATER THAN THRESH.
    = JMP =*&2                          =NO
    = JMP =A43                          =YES
    = LDA ='713                         =GET EFF. SUCC.
    = SKG =LCCN&1                       =IS IT GREATER THAN THRESH.
    = JMP =A44                          =NO
A43 = CRA =                             =MAKE VOCAL CORD VALUE ZERO
    = JMP =A45
A44 = LDA =LCIC
A45 = NOP =
    = STA ='677                         =STORE VOCAL CORD IN XCEL
******************************************************************************
A46 = NOP =                             =START PRINT STORAGE
    = LDA ='664
    = STA =ACFL                         =STORE MASK FLAG
    = LDA ='665
    = STA =ACFL&1                       =STORE HEART ARREST FLAG
    = LDA ='666
    = STA =ACFL&2                       =STORE FIBRILLATION FLAG
    = LDX =-10,1
A47 = LDA =ACFL&10,1
```

```
    = JZE =A48                =IS ACTUATION FLAG SET,NO
    = LDA =PRFL&10,1          =YES
    = JZE =*&2                =IS PRINT FLAG SET,NO
    = JMP =A49                =YES
    = LDA ='760               =GET TIME
    = ORA =CODE&10,1          =INSERT CODE
    = CALL=PSTR               =GO STORE ENTRY
    = LDA =ONE
    = STA =PRFL&10,1          =SET PRINT FLAG
    = JMP =A49
A48 = LDA =PRFL&10,1
    = JZE =A49                =IS PRINT FLAG SET,NO
    = LDA ='760               =GET TIME
    = ORA =CODE&10,1          =INSERT CODE
    = ORA =NEGS               =INSERT NEG. SIGN
    = CALL=PSTR
    = CRA =
    = STA =PRFL&10,1          =RESET PRINT FLAG
A49 = JXI =A47,1
AXX = LDX =**,1               =RESTURE INDEX
    = JMP*=A1                 =RETURN
**********************************************************************
ACFL= OCT =0,0,0,0,0,0,0,0,0,0
ABMK= OCT =37777777
AIRM= DEC =1.0B11
AIRT= DEC =2B11
AMIN= DEC =0.5B11
AMLT= DEC =36.3B11,18.2B11,27.2B11
ARFL= OCT =0
ATE1= DEC =2.6B11
ATE2= DEC =.275B11
ATH1= DEC =1.65B11
ATH2= DEC =1.1B11
ATHR= DEC =2.2B11
AWIF= OCT =0
AYMK= OCT =1000
BKAD= PZE =BUCK
BKFL= OCT =0
BRAD= PZE =BRON
BRON= PZE =BRB0
    = PZE =BRB1
    = PZE =BRB2
    = PZE =BRB3
BUCK= PZE =BUK0
    = PZE =BUK1
```

4

```
     = PZE =BUK2
     = PZE =BUK3
 BUFL= OCT =0
 CCCN= DEC =15B11,.045B0
 CCFS= DEC =100B11
 CODE= OCT =14000000,15000000,16000000,17000000,20000000
     = OCT =21000000,22000000,23000000,24000000,25000000
 CO2A= DEC =80B11
 CO2M= DEC =35B11
 CUV = OCT =0,0,0,0
 DCCN= DEC =.00033B0
 DECO= OCT =0300,0400,1500,1600,1700,2400,0,0,0,0
 DEIC= DEC =4B11
 DECN= DEC =.33B11,1.33B14,.5B11,4.5B11
 DESM= DEC =10.0B11
 DETM= OCT =0
 DFLG= OCT =0
 DPS = OCT =0
 DPD = OCT =0
 DPR = OCT =0
 DPSB= OCT =0
 DPDB= OCT =0
 DPRB= OCT =0
 DSPS= OCT =0
 DSPD= OCT =0
 DSPR= OCT =0
 FHCN= DEC =22B11,2.6B11,1.1B11,.205B0,.55B11
 FHFS= DEC =100B11
 FHIC= DEC =33B11
 FSFL= OCT =0
 FTIM= OCT =0
 FTMX= OCT =0
 INFL= OCT =0
 IRFL= OCT =0
 LCCN= DEC =.55B11,11B11
 LCFS= DEC =100B11
 LCIC= DEC =50B11
 LRAD= PZE =LARX
 LARX= PZE =LAR0
     = PZE =LAR1
     = PZE =LAR2
     = PZE =LAR3
 LRFL= OCT =0
 MANU= PZE =MAN
 MAN = PZE =MAN0
```

```
    = PZE =MAN2
    = PZE =MAN1
    = PZE =MAN3
MFFL= OCT =0
NEGS= OCT =400CC000
NLMT= DEC =-100B11,-10CB11,-200B11,-200B11
NUCH= DEC =.03333B11,.0333B11,.02167B11,.02B11
CNE = DEC =1B11
02MN= DEC =5B11
PCON= DEC =80B11,40B11,60B11
PLMT= DEC =&10CB11,&100B11,&200B11,&200B11
PRFL= OCT =0,0,C,0,0,0,0,0,0,0
SAFL= OCT =0
SCFL= OCT =0
STFL= OCT =0
STH1= DEC =5.5B11
STH2= DEC =11.CB11
STH3= DEC =15.0B11
SUCI= DEC =2B11,1.5B11,1.0B11,0
SWMK= OCT =3
TBK1= DEC =10
TBK2= DEC =20
TBUK= OCT =0
TBLN= OCT =0
TBL1= DEC =50
TBL2= DEC =60
TECN= DEC =.38C,1.0825B11,3.636B11,.33B0,11B11,.092B11
TEFS= DEC =100B11
TETM= OCT =0
TEMP= OCT =0
TIMF= DEC =300,200,150,100
TJCN= DEC =.04545B0,.2B0
TJFS= DEC =100B11
TJIC= DEC =100B11
TJTM= OCT =0,0
TMP = OCT =0
UDCH= DEC =.2222B11,.2B11,.1533B11,.40B11
UPCN= DEC =.02BC
USPS= OCT =0
USPD= OCT =0
USPR= OCT =0
     = NOP =
     = NOP =
     = END =A0
```

```
00763 CARDS READ.
*
*   =     =                      ANALOG  INPUT/OUTPUT SUBROUTINE
*   =     =                        A=FIRST ADDRESS OF INPUT OR OUTPUT
*   =     =                        B=FIRST ADDRESS OF SCALING CONSTANTS
*   =     =                          IF ZERO- NO SCALING
*   =     =                          IF SCALE CONST. IS ZERO-NO SCALING
*   =     =                       CALL&1= MZE FFLL  -MZE MEANS A TO D
*   =     =                             = PZE FFLL  -PZE MEANS D TO A
*   =     =                               FF IS FIRST CHANNEL
*   =     =                               LL IS LAST CHANNEL
*   =     =
 ANIO= NTRY=ANO
     = REL =
 ANO = JMP =**
     = STD =AST
     = STB =BST
     = STB =SCFG                     =STORE  A AND B
     = LDA*=ANO
     = STA =IORO                     =STORE INPUT OR OUTPUT INDICATOR
     = ANA =CMSK
     = STA =LCHN                     =STORE LAST CHANNEL
     = LDA =IORO
     = ARS =6
     = ANA =CMSK
     = STA =CHAN                     =STORE CURRENT CHANNEL
     = OCP ='1010
     = OCP ='1011
     = OCP ='1012
     = OCP ='1013                    =ENABLE I/O CHANNELS
     = IRX =ANO                      =STEP RETURN ADDRESS
     = LDA =IORO
     = JPL =AN4                      =DETERMINE INPUT OR OUTPUT
     = LDA =CHAN
     = LGL =18
     = STA =CHAN                     =SHIFT CHAN. TO HIGH ORDER
     = IRX =LCHN                     =STEP LAST CHAN.
     = LGL =18
     = STA =LCHN                     =SHIFT TO HIGH ORDER
     = LDA =AST
     = SUB =ONE
     = STA =AST
     = LDA =BST
     = SUB =ONE
     = STA =BST                      =DECREASE STORAGE AND CONST. ADDRESSES
```

```
    = LDA =CHAN
    = LGL =1
    = ORA =ADCO                      =SET UP FOR FIRST CHAN.
AN1 = OCP =2
    = OTA =                          =START A-D CONVERSION
    = IRX =AST
    = IRX =BST
    = LDA =CHAN
    = ADD =STPC
    = STA =CHAN                      =STEP CHANNEL NUMBER
    = LGL =1                         =POSITION
    = ORA =ADCO
    = STA =SELM                      =SET UP FOR NEXT CHANNEL SELECTION
    = OCP =1                         =ENABLE INPUT
    = SKS ='30002                    =TEST CONVERSION COMPLETE
    = JMP =*&2
    = JMP =*-2
    = OCP ='1016                     =READOUT TO I/O BUFFER
    = INM =ATOC                      =INPUT ANALOG VOLTAGE
    = LDA =SCFG
    = JZE =AN2                       =IS SCALING FLAG ZERO,YES
    = LDA*=BST                       =NO
    = JZE =AN2                       =IS SCALING CONST. ZERO,YES
    = TAB =                          =NO
    = MPY =ATOC                      =SCALE INPUT
    = JMP =AN3
AN2 = LDA =ATOC
AN3 = STA*=AST                       =STORE SCALED INPUT
    = LDA =CHAN
    = SKN =LCHN                      =HAS END OF INPUT BEEN REACHED
    = JMP*=ANO                       =YES,RETURN
    = LDA =SELM                      =NO
    = JMP =AN1                       =GO DO NEXT MUX CHANNEL
AN4 = NOP =                          =OUTPUT (D TO A)
    = OCP =2
    = IRX =CHAN
    = IRX =LCHN                      =STEP CHANNEL NUMBERS
    = SKS ='40400                    =RESET OVERFLOW IND.
    = NOP =
AN5 = LDA =SCFG
    = JZE =AN7                       =IS SCALING FLAG ZERO,YES
    = LDA*=BST                       =NO
    = JZE =AN7                       =IS SCALE CONSTANT ZERO,YES
    = TAB =                          =NO
    = MPY*=AST                       =SCALE OUTPUT
    = ALS =11              =SHIFT FOR OUTPUTTING
    = SKS ='40400          =IS OVERFLOW SET
    = JMP =*&2             =YES
    = JMP =AN8             =NO
    = JPL =AN6             =IS OUTPUT POSITIVE,YES
    = LDA =NMAX            =NO,PICK UP NEGATIVE MAX.
    = JMP =AN8
AN6 = LDA =PMAX            =PICK UP POSITIVE MAX.
    = JMP =AN8
AN7 = LDA*=AST             =PICK UP UNSCALED OUTPUT
    = ANA =NMAX            =STRIP OUT DAC VALUE BITS
AN8 = STA =OVAL            =STORE OUTPUT
    = LDA =CHAN
    = SKN =LCHN            =HAS LAST OUTPUT BEEN REACHED
    = JMP =AN9             =YES
    = ORA =DACL            =NO,INSERT DAC LOAD CODE
    = ORA =OVAL            =INSERT OUTPUT VALUE
    = OTA =                =START CONVERSION
    = IRX =CHAN            =STEP CHANNEL
    = IRX =AST
    = IRX =BST             =STEP ADDRESSES
    = JMP =AN5             =GO DO NEXT DAC CHANNEL
AN9 = ORA =DACT            =INSERT DAC TRANSFER CODE
    = ORA =OVAL            =INSERT OUTPUT VALUE
    = OTA =                =START CONVERSION
    = SKS ='30004          =TEST FOR TRANSFER COMPLETE
    = JMP =*&2
    = JMP =*-2
    = JMP*=AN0             =RETURN
AST = OCT =0
BST = OCT =0
SCFG= OCT =0
IORU= OCT =0
CHAN= OCT =0
LCHN= OCT =0
SELM= OCT =0
ATOD= OCT =0
CVAL= OCT =0
CMSK= OCT =77
ONE = OCT =1
ADCO= OCT =2000
DACL= OCT =2100
DACT= OCT =2300
STPC= OCT =01000000
NMAX= OCT =77774000
PMAX= OCT =37774000
SPRA= BSS =4
    = END =AN0
```

```
00137 CARDS READ.
*
*    =      =                             LEAD TRANSFER FUNCTION
*    =      =                               A CONTAINS  INPUT
*    =      =                               B CONTAINS STORAGE ADDRESS
*    =      =                               CALL&1 CONTAINS DELTAT/TAU
*    =      =                               OUTPUT IN A
LEAD= NTRY=LED
    = REL =
LED = JMP =**
    = STB =LDSA                          =STORE  STORAGE ADDRESS
    = SUB*=LDSA                          =FORM LEAD OUTPUT
    = STA =LDO                           =STORE OUTPUT
    = TAB =
    = MPY*=LED                           =FORM OUTPUT*DELTAT/TAU
    = ADD*=LDSA                          =ADD OLD STORAGE
    = STA*=LDSA                          =UPDATE STORAGE CELL
    = IRX =LED                           =PREPARE TO RETURN
    = LDA =LDO                           =PUT OUTPUT IN A
    = JMP*=LED                           =RETURN
LDSA= OCT =0
LDC = OCT =0
    = END =LED
```

```
00022 CARDS READ.
*
*    =       =                 LAG TRANSFER FUNCTION
*    =       =                   A CONTAINS INPUT
*    =       =                   B CONTAINS STORAGE ADDRESS
*    =       =                   CALL&1 CONTAINS DELTAT/TAU
*    =       =                   OUTPUT IN A
LAG  = NTRY=LAGO
     = REL  =
LAGO= JMP  =**
     = STB  =LGSA             =STORE STORAGE ADDRESS
     = SUB*=LGSA             =FORM INPUT-OLD OUTPUT
     = TAB  =
     = MPY*=LAGO             =MULTIPLY BY DELTAT/TAU
     = ADD*=LGSA             =ADD OLD OUTPUT STORAGE
     = STA*=LGSA             =UPDATE STORAGE CELL
     = IRX  =LAGO             =PREPARE TO RETURN
     = LDA*=LGSA             =PUT OUTPUT IN A
     = JMP*=LAGO             =RETURN
 LGSA= OCT  =0
     = END*=LAGO
```

```
00020 CARDS READ.
*
*    =      =              =FUBR-FUNCTION GENERATOR
*    =      =              =     -A CONTAINS X COORDINATE
*    =      =              =     -B CONTAINS TABLE START ADDRESS
*    =      =              =     -RESULT IN A AFTER ROUTINE
*    =      =              =     -TABLE CONTAINS THE NUMBER OF
*    =      =              =        BREAKPOINTS FOLLOWED BY THE
*    =      =              =        X AND Y COORDINATES OF THE
*    =      =              =        BREAKPOINTS.
FUBR= NTRY=FUBO
    = REL =
FUBO= JMP =**
    = STX =FUBX,1          =STORE INDEX
    = STA =XCOR            =STORE X COORDINATE
    = STB =TBAD            =STORE TABLE ADDRESS
    = LDA =IMSK
    = SUB*=TBAD
    = ADD =ONE
    = TAX =,1              =SET UP INDEX FOR NUMBER OF ENTRIES
    = IRX =TBAD
    = STD =PU1
    = STD =PU2             =SET UP PICKUP INSTR. ADDRESSES
    = IRX =TBAD
    = STD =PUY1            =SET UP Y1 COORD. PICKUP
PU1 = LDA =**              =PICKUP X1
    = SKG =XCOR            =IS X1 GREATER THAN X COOD.
    = JMP =PU2             =NO
PUY1= LDA =**              =PICK UP Y1
FUBX= LDX =**,1            =RESTORE INDEX
    = JMP*=FUBO            =EXIT
PU2 = LDA =**              =PICK UP X TABLE ENTRY
    = SKG =XCOR            =IS IT GREATER THAN X COORD.
    = JMP =*&2             =NO
    = JMP =FUB2            =YES
    = STA =XA              =STORE XA
    = IRX =PU2
    = STD =PUYA            =SET UP FOR YA PICKUP
    = IRX =PU2             =SET UP FOR NEXT X PICKUP
    = JXI =PU2,1           =HAS END OF TABLE BEEN REACHED,NO
PUYA= LDA =**              =PICK UP LAST Y ENTRY
    = JMP =FUBX            =GO TO EXIT
FUB2= SUB =XA
    = STA =XBXA            =STORE XB-XA
    = LDA =PU2
```

```
     = ADD =ONE
     = STD =*&1
     = LDA =**                    =PICK UP YB
     = SUB*=PUYA
     = STA =YBYA                  =STORE YB-YA
     = CRA =
     = TAB =                      =CLEAR B
     = LDA =XCOR
     = SUB =XA                    =FORM X-XA
     = DIV =XBXA                  =FORM X COORD. RATIO AT B0
     = MPY =YBYA                  =MULTIPLY BY YB-YA
     = RND =
     = ADD*=PUYA                  =ADD YA
     = JMP =FUBX                  =GO TO EXIT
XCOR= OCT =0
TBAD= OCT =0
IMSK= OCT =77777
ONE = OCT =1
XA  = OCT =0
XBXA= OCT =0
YBYA= OCT =0
    = END =FUB0
```

```
00066 CARDS READ.
*
*    =       =                    PSTR-PRINT STORAGE ROUTINE
*    =       =                       A-CONTAINS TIME & CODE
*    =       =                       B-CONTAINS VALUE
PRIN= NTRY=PO
PSTR= NTRY=PS
    = REL =
PS  = JMP =**
    = STA*='667                   =STORE IN NEXT PRINT STORAGE ADDR.
    = ANA =CDMK                   =STRIP OUT CODE
    = SKG =CDTH                   =DOES THIS CODE REQUIRE A VALUE
    = JMP =*&2                    =YES
    = JMP =*&3                    =NO
    = IRX ='667                   =STEP STORAGE ADDRESS
    = STB*='667                   =STORE VALUE
    = IRX ='667                   =STEP STORAGE ADDR. FOR NEXT ENTRY
    = SKG =LSCL                   =HAS END OF STORAGE BEEN REACHED
    = JMP*=PS                     =NO,EXIT
    = HLT ='13                    =YES
    = JMP*=PS
CDMK= OCT =3700000O
CDTH= OCT =07000000
LSCL= OCT =660
*    =       =                     PRIN-PRINT ROUTINE
*    =       =                          -PRINTS HEADINGS AND ENTRIES IN
*    =       =                          -EVENT STORAGE
PO  = JMP =**
    = STX =P6,1
    = SKS ='60004                 =IS PRINT S.L. SET
    = JMP =*&2                    =YES
    = JMP =P6                     =NO,GO TO EXIT
    = SKS ='60004                 =IS PRINT S.L. STILL SET
    = JMP =*&2                    =YES
    = JMP =P6                     =NO,GO TO EXIT
    = LDA ='667                   =GET NEXT PRINT STORAGE ADDRESS
    = SKN =PRIA                   =IS NPSA AT INITIAL VALUE
    = JMP =P6                     =YES,GO TO EXIT
    = OCP ='1015                  =NO,TURN ON PRINT LIGHT
    = LDA =HEDA
    = LDB =HEDB
    = JST =OUT                    =PRINT HEADING
    = LDA =PRIA
    = STA =CPRA                   =INITIALIZE CURRENT PRINT ADDR.
P1  = LDA*=CPRA                   =GET PRINT ENTRY
```

```
      = ANA =TMSK                         =STRIP OUT TIME
      = TAB =                             =START TIME CONV. AND PRINT
      = CRA =
      = DIV =TEN                          =CONVERT TIME TO SECONDS
      = CRA =
      = DIV =SXTY                         =CONVERT TO MINUTES
      = STA =SEC                          =STORE BINARY SECONDS
      = IAB =
      = JST =BD                           =CONVERT MINUTES TO BCD
      = LGL =12
      = ORA =BAS1                         =INSERT COLON
      = STA =PWRD
      = LDA =SEC
      = JST =BD                           =CONVERT SECONDS TO BCD
      = LGL =6
      = ANA =SCMK                         =MASK BCD SEC.
      = ORA =BAS2                         =INSERT LOWER CASE
      = STA =PWRD&1
      = LDA =PWAD
      = LDB =TMPB
      = JST =OUT                          =PRINT TIME
      = LDA*=CPRA                         =GET PRINT ENTRY
      = ARS =18
      = ANA =TMSK                         =STRIP OUT CODE
      = STA =CODE
      = ADD =MSZA                         =FORM MESSAGE ADDRESS
      = STD =*&1
      = LDA*=**                           =GET MESSAGE ADDRESS
      = LDB =MSCB                         =GET MS FORMAT-3 SPACES&6WORDS
      = JST =OUT                          =PRINT MESSAGE
      = LDA =CODE                         =GET CODE
      = SKG =CDT3                         =IS IT GREATER THAN THRESH. 3
      = JMP =P2                           =NO
      = LDA*=CPRA                         =YES,GET ENTRY
      = JPL =*&3                          =IS ENTRY POSITIVE,YES
      = LDA =OFF                          =NO
      = JMP =*&2
      = LDA =ON
      = STA =PWRC
      = LDA =PWAD
      = LDB =OOCB                         =FORMAT ON,OFF-1 WORD
      = JST =OUT                          =PRINT ON OR OFF
      = JMP =P3
P2    = SKG =CDT2                         =IS CODE GREATER THAN THRESH. 2
      = JMP =*&2                          =NO
```

```
     = JMP =P3                     =YES
     = IRX =CPRA                   =STEP ENTRY ADDRESS
     = LDA =CODE
     = SKG =CDT1                   =IS CODE GREATER THAN THRESH. 1
     = JMP =*&3                    =NO
     = LDA =MILG                   =YES
     = JMP =*&2
     = LDA =LITR
     = STA =PWRC&2                 =SET UP FOR LITERS OR MG.
     = LDA*=CPRA                   =GET VALUE AT B11
     = ARS =12                     =STRIP OUT INTEGRAL PART
     = JST =BD                     =CONVERT TO BCD
     = STA =PWRC
     = LDA*=CPRA                   =GET VALUE
     = ANA =FRCM                   =STRIP OUT FRACTIONAL PART
     = JST =BDFR                   =CONVERT TO BCD
     = STA =PWRC&1
     = LDA =PWAC
     = LDB =VALB                   =FORMAT- 4 SPACES& 3 WORDS
     = JST =OUT                    =PRINT VALUE
P3   = IRX =CPRA                   =STEP ENTRY ADDRESS
     = SKN ='667                   =TIME TO STOP PRINT
     = JMP =*&2                    =YES
     = JMP =P1                     =NO
     = LDA ='762                   =GET HOLD FLAG
     = JZE =P4                     =IS IT SET,NO
     = LDA =HOLC                   =YES
     = STA =PWRC
     = LDA =SPAC                   =GET 4 SPACES
     = STA =PWRC&1
     = JMP =P5
P4   = LDA =END
     = STA =PWRC
     = LDA ='663                   =GET RUN NO.
     = JST =BD                     =CONVERT RUN NO. TO BCD
     = STA =PWRC&1
     = IRX ='663                   =STEP RUN NO.
P5   = LDA =CRET                   =GET 4 CR
     = STA =PWRC&2
     = LDA =PWAC
     = LDB =LSTB
     = JST =OUT                    =PRINT HOLD OR END & RUN NO.& 4 CR
P6   = LDX =**,1                   =RESTORE INDEX
     = OCP ='1012
     = OCP =2
     = OTM =DE24                            =TURN OFF PRINT LIGHT
     = JMP*=P0                              =EXIT
BAS1= OCT =00007504
BAS2= OCT =740C0000
CDT1= OCT =3
CDT2= OCT =7
CDT3= OCT =13
CODE= OCT =0
CPRA= OCT =0
CRET= OCT =76767676
DE24= OCT =3000
END = OCT =65456456
FRCM= OCT =7777
HEDA= PZE =HEAD
HEDB= OCT =510240
HEAD= BCI =8,ANESTHESIOLOGICAL TRAINER RECORD
HCR1= OCT =76121212
HED1= BCI =10, STUDENT&4,,,,,,,,,,,,,,,,,,-INSTRUCTOR&4
    = BCI =9,,,,,,,,,,,,,,,,,,,,,,,-DATE&4,,,,,,,,,-
HCR2= OCT =76121212
HED2= BCI =11,TIME                EVENT                        REMARKS.
HOLD= OCT =70464364
LITR= OCT =43735656
LSTB= OCT =400014
MILG= OCT =44677356
MSCB= OCT =103030
MSZA= PZE =MA00
MA00= PZE =MS00
MA01= PZE =MS01
MA02= PZE =MS02
MA03= PZE =MS03
MA04= PZE =MS04
MA05= PZE =MS05
MA06= PZE =MS06
MA07= PZE =MS07
MA08= PZE =MS08
MA09= PZE =MS09
MA10= PZE =MS10
MA11= PZE =MS11
MA12= PZE =MS12
MA13= PZE =MS13
MA14= PZE =MS14
MA15= PZE =MS15
MA16= PZE =MS16
MA17= PZE =MS17
```

```
MA18= PZE =MS18
MA19= PZE =MS19
MA20= PZE =MS20
MA21= PZE =MS21
MS00= BCI =6,OXYGEN FLOW                 .
MS01= BCI =6,N2O FLOW                    .
MS02= BCI =6,CYCLOPROPANE FLOW           .
MS03= BCI =6,VERNITROL FLOW              .
MS04= BCI =6,PENTOTHAL INJECTED          .
MS05= BCI =6,SUCCINYLCHOLINE INJECTED.
MS06= BCI =6,METHOXAMINE INJECTED        .
MS07= BCI =6,EPHEDRINE INJECTED          .
MS08= BCI =5,BREATHING STOPPED$          .
MS09= BCI =5,BREATHING STARTED$          .
MS10= BCI =4,AIRWAY ATTACHED$            .
MS11= BCI =4,AIRWAY REMOVED$             .
MS12= BCI =2,MASK$                       .
MS13= BCI =4,HEART ARREST$               .
MS14= BCI =4,FIBRILLATION$               .
MS15= BCI =6,RIGHT BRONCHUS BLOCK$       .
MS16= BCI =5,LEFT BRONCHUS BLOCK$        .
MS17= BCI =2,BUCKING$                    .
MS18= BCI =4,LARYNGOSPASM$               .
MS19= BCI =3,LIP PINCH$                  .
MS20= BCI =4,FASCICULATION$              .
MS21= BCI =3,ARRHYTHMIA$                 .
OFF = OCT =40466666
ON  = OCT =40464556
COCR= OCT =4
PRIA= OCT =405
PWAD= PZE =PWRD
PWRD= OCT =0,0,0
SCMK= OCT =00777700
SEC = OCT =0
SPAC= OCT =56565656
SXTY= DEC =60
TMPB= OCT =400007
TMSK= OCT =00077777
VALB= OCT =104014
    = NOP =
*   =     =        OUT-GENERALIZED OUTPUT TO PUNCH OR TYPEWRITER
*   =     =             FORMAT CODE IN B IS CNNLLL  (SEE PT00)
*   =     =             END OUTPUT ON DOLLAR SIGN
OUT = JMP =**
    = STX =PT9,1                 =STORE INDEX
```

```
      = STD =PT5                     =SET STARTING ADDRESS
      = LDX =6,1
      = LLS =5
      = JPL =*&2
      = ADX =-3,1
      = STX =PT7,1
      = LDX =-4,1
      = JPL =*&2
      = ADX =-4,1
      = STX =PT4,1
      = LLR =1
      = OCP =0
      = SKS ='2000
      = JMP =*-1
 TORP= OCP ='2010                    =SELECT DEVICE
  PT1 = CRA ='76
      = LLS =1
      = JPL =*&2                     =TEST CODE FOR CRT
      = OTM =PT1                     =OUTPUT CARRAIGE RETURN
      = JZE =*&2                     =TEST CODE FOR TAB
      = OTM =PT2                     =OUTPUT TAB
      = LLR =1
  PT2 = CRA ='36
      = LLS =6
      = JPL =PT3                     =TEST CODE FOR SPACE
      = JZE =PT3                     =TEST NR SPACES ZERO
      = OTM =PT3                     =OUTPUT SPACE
      = ADD =ONE                     =DECREMENT NR SPACES
      = JMP =*-3                     =REPEAT
  PT3 = CRA ='56
      = LLS =9                       =SET LIMIT
      = STD =LMIT
  PT4 = LDX =**,1                    =SET CHAR WORD CTR
  PT5 = LDB =**                      =PICK UP WORD
  PT6 = LDA =LMIT                    =TEST LIMIT FOR ZERO
      = JZE =PT8
      = SUB =ONE                     =DECREMENT LIMIT
      = STA =LMIT
      = CRA =
  PT7 = LLR =**
      = SKN =DOLS                    =END OUTPUT ON DOLLAR SIGN
      = JMP =PT8
      = OTA =                        =OUTPUT CHARACTER
      = JXI =PT6,1                   =STEP AND TEST CHAR WORD
      = IRX =PT5                     =STEP STARTING ADDRESS
```

```
     = JMP =PT4                      =REPEAT
PT8  = SKS ='2000
     = JMP =*-1
     = OCP ='2070                    =STOP DEVICE
PT9  = LDX =**,1                     =RESET INDEX
     = JMP*=OUT                      =RETURN
ONE  = OCT =1
DOLS= OCT =53
LMIT= OCT =0
BDFR= JMP =**                        =BIN-DEC CONVERSION-FRACTIONAL PART
     = TAB =
     = LLS =11                       =SET BINARY POINT AT B0
     = MPY =TEN
     = LGL =12                       =POSITION MSD
     = ORA =FRMK
     = STA =TEMP
     = MPY =TEN
     = LGL =6                        =POSITION LSD
     = ORA =TEMP
     = JMP*=BDFR
FRMK= OCT =73000056
TEMP= OCT =0
BD   = JMP =**                       =BINARY TO DECIMAL CONVERSION(3 DIGITS)
     = TAB =
     = CRA =
     = STA =TEMP
     = DIV =TEN
     = STA =TEMP
     = CRA =
     = DIV =TEN
     = ALS =6
     = ORA =TEMP
     = STA =TEMP
     = LLR =36
     = JZE =ZERO
     = JMP =RET
ZERO= ORA =CP1
RET  = ORA =CP2
     = ORA =TEMP
     = JMP*=BD
TEN  = DEC =10
CP1  = OCT =560000
CP2  = OCT =56000000
     = END =PS
```

```
C0313 CARDS READ.
*
*    =       =                           TRANSPORT DELAY
*    =       =                             A=INPUT VALUE AND OUTPUT AFTER ROUT.
*    =       =                             I=-DELAY LINE NUMBER
CDLA= NTRY=D0
DLAY= NTRY=D1
     = REL =
D0   = JMP =**
     = LDX =-128,1
     = CRA =
     = STA =LINE&128,1
     = JXI =*-1,1
     = CRA =
     = TAB =                            =CLEAR B
     = CRA =
     = STA =MODI
     = LDA =CON1
     = STA =MODO                        =INITIALIZE MODULUS COUNTERS
     = JMP*=D0                          =EXIT
D1   = JMP =**
     = STX =D2,1                        =STORE INDEX
     = ADX =10,1
     = STX =LNNO,1                      =FORM LINE NUMBER
     = STA =TIN                         =STORE INPUT IN TEMP
     = LDB =LNNO
     = MPY =CON2
     = IAB =
     = ADD =FRST
     = STA =LADO                        =FORM LINE ADDRESS ZERO
     = ADD =MODI
     = STA =INL                         =FORM INPUT ADDRESS
     = LDA =TIN
     = STA*=INL                         =STORE INPUT IN LINE
     = LDA =LADO
     = ADD =MODO
     = STA =OUTL                        =FORM OUTPUT ADDRESS
     = LDA =LNNO
     = SKN =CON3                        =TIME TO STEP MODULUS COUNTS
     = JMP =*&2                         =YES
     = JMP =D2                          =NO
     = IRX =MODI
     = ANA =MASK
     = STA =MODI                        =STEP INPUT COUNT
     = IRX =MODO
     = ANA =MASK
     = STA =MODO                =STEP OUTPUT COUNT
D2   = LDX =**,1                =RESTORE INDEX
     = LDA*=OUTL                =PICK UP OUTPUT
     = JMP*=D1                  =EXIT
MODI= OCT =0
MODO= OCT =0
LNNO= OCT =0
INL = OCT =0
CUTL= OCT =0
LADO= OCT =0
TIN = OCT =0
CON1= DEC =12
CON2= DEC =32
CON3= DEC =9
MASK= OCT =37
FRST= PZE =LINE
LINF= BSS =128
     = END =DO
```

-BR
SE

FROM:
ERIC FACILITY
SUITE 601
1735 EYE STREET, N. W.
WASHINGTON, D.C. 20006

AEROJET
GENERAL TIRE
GENERAL

AEROJET-GENERAL CORPORATION